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Fissile Materials Disposition Program

Alternative Technical Summary Report: Electrometallurgical Treatment Variant

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University of California
Lawrence Livermore
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Acknowledgments

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Executive Summary

The Department of Energy (DOE) is examining options for placing weapons-usable surplus nuclear materials, principally plutonium (Pu) and highly enriched uranium (HEU), in a form or condition that is inherently unattractive and inaccessible for use in weapons either by the host country or by a subnational group. The potential environmental impacts of technologies to implement this objective for plutonium are described in the Fissile Materials Disposition (MD) Program's *Storage Disposition of Weapons-Usable Fissile Materials Programmatic Environmental Impact Statement* (PEIS).

The MD PEIS examined the following resource areas: land use, facility operations and site infrastructure; air quality and acoustics; water, geology and soils, biotic, cultural and paleontological resources; socioeconomics; human health, normal operations and facility accidents; waste management; and transportation.

The PEIS is only part of the process of arriving at a Record of Decision (ROD) for the Fissile Materials Disposition Program (FMDP). In Phase I of this process, a number of options were eliminated from further consideration. The surviving options can be grouped into three groups of variants treated as reasonable in the PEIS:

1) Plutonium burning in a once-through reactor cycle as mixed oxide (MOX) fuel followed by disposal in a repository,

2) Immobilization or fixation in an acceptable matrix to create an environmentally benign form for disposal in a repository, and

3) Disposal in deep bore holes (with or without prior fixation).

In Phase II of this process, variants of these alternatives are being examined in more detail to provide more complete information desired for an ROD which includes consideration of technical viability, cost, schedule, and other factors.

One purpose of Phase II documents is to provide the required information for the technical cost and schedule analyses of the baseline variants plus their optional approaches. The purpose of this specific document is to provide the required information for one of the immobilization variants, the Electrometallurgical Treatment (ET) variant. The alternative and the variant are the same for the electrometallurgical process.

Immobilization is the fixation of surplus fissile materials, in this case plutonium, in an acceptable matrix to create an environmentally benign form for disposal in a repository. In addition to the traditional characteristics required of an immobilization form to achieve isolation of the plutonium from the biosphere over geologic time periods, the immobilization form for the MD Program must also possess the property that it is inherently as unattractive and inaccessible as the fissile material from spent

commercial fuel. This latter requirement is similar to the wording of the "spent fuel standard" invoked in the National Academy of Sciences (NAS) study on plutonium disposition. From this perspective, high-level wastes (HLW) or separated cesium (^{137}Cs), can be added with the fissile material into the waste form to create a radiation field which can serve as a proliferation deterrent.

The immobilization technology considered here is to place the plutonium in a monolithic mineral form called glass-bonded zeolite (GBZ) and then dispose of the GBZ plutonium in a federal repository. This immobilization process is shown conceptually in Figure 1 and discussed in Section 1. GBZ is an amorphous material formed by sorbing a salt containing plutonium onto zeolite, mixing the zeolite with a suitable glass frit, and hot pressing to form the GBZ.

Using electrometallurgical treatment and the GBZ waste form offers a simple design and compact equipment. The ET electrorefiner can treat fuel alloys that are problems for aqueous processors. Incorporation of plutonium into GBZ containing either spent fuel fission products or ^{137}Cs would provide a form that would be relatively easy to store but would render retrieval of the plutonium more difficult. Many of the technologies needed to prepare Pu-GBZ with a proliferation resistant cesium or fission produced radiation spike exist today. Most of the technical risk associated with this alternative is due to a small experience base of several unit processes with pure plutonium. Questions such as the glass frit formulation, plutonium solubility, plutonium dissolution kinetics, optimum neutron absorber, the solubility interaction of the neutron absorber and plutonium, equipment design for criticality control, and accountability after spiking with ^{137}Cs or fission products remain to be solved. Some technical issues have been addressed in various studies and in various degrees of completeness. Research and development activities are required to prove the process to be viable and cost effective for disposal in a repository. The desired form of the final product will determine the extent of technical issues such as long-term criticality safety and stability of the product after repository emplacement.

In the electrometallurgical treatment variant, the disposition process begins with the transportation of plutonium feed materials (pits, metal, oxides, unirradiated reactor fuel, etc.) to the disassembly, conversion, and immobilization facility site in DOT shipping containers. When required each shipping container provides double containment of the contents.

The shipping containers will be unpacked, and accountability measurements will be conducted. The plutonium materials will then be converted to plutonium chloride using a dry feed preparation process ($PuCl_3$) in a solution of LiCl-KCl eutectic salt. The salt is sorbed in zeolite, mixed with a suitable glass frit and ^{137}Cs and fission product radiation spike and then hot pressed to form the GBZ waste form. The radiation spike is sufficient to maintain a radiation field above 1 Gy (100 rad) per hour at 1 m (3 ft) for a period of about 30 to 60 years. Once the GBZ material has been formed, recovery of the plutonium will require extensive processing to return it to a state readily transformed to weapons. These canisters will be stored in a surface storage facility onsite until

transferred to the HLW repository. The repository is expected to be open for 100 years and then be sealed. Since the radiation barrier will be decaying with a 30-year half-life, safeguards will be necessary during the period that the repository is open. Once the repository is sealed, then the sealed repository is expected to provide the necessary proliferation deterrent. Postclosure monitoring (e.g., satellite surveillance or seismic monitors) is expected to contribute to the proliferation resistance of the immobilization disposition variants.

This immobilization variant assumes an integrated, but not concurrent, campaign with operations to treat Department of Energy owned spent fuels in the ANL-W hot cells. Costs are also estimated for a secondary case for simultaneous plutonium disposition and spent fuel treatment.

Section 2 examines technical issues associated with each step of the immobilization process from front-end processing to the final repository. This disposition variant is qualitatively assessed against the following eight criteria:

- Resistance to theft and diversion
- Resistance to retrieval by the host nation
- Technical viability
- Environment, safety, and health compliance
- Cost effectiveness
- Timeliness
- Fosters progress with Russia and others
- Public and institutional acceptance.

This end-to-end immobilization variant combines functions from facilities previously described in and bounded by the PEIS process currently underway. For front-end processing in this variant, elimination of aqueous recovery lines results in significant reductions in aqueous waste solutions, processing equipment, associated facility space, utilities, and support systems. The need for new facilities is reduced due to the availability of existing facilities at ANL-W.

1.0 Variant Description

1.1 Introduction

Immobilization is the fixation of the surplus fissile materials in an acceptable matrix such as glass or ceramics to create an environmentally benign form for disposal in a repository. In addition to the traditional characteristics required of an immobilization form to achieve isolation of the fissile material from the biosphere over geologic times, the immobilization form for the Fissile Materials Disposition Program (FMDP) must also possess the property that it is inherently as unattractive and inaccessible as the fissile material from commercial spent fuel. This latter requirement is similar to the wording of the "spent fuel standard" invoked in the National Academy of Sciences (NAS) study on plutonium disposition. High-level wastes (HLW) or separated cesium (^{137}Cs), can be added with the fissile material into the waste form to create a radiation field that increases the proliferation resistance and decreases reuse by the host nation in the following ways:

- Plutonium will be diluted with elements that must be removed by extensive chemical processing to return it to weapons-usable purity.
- The immobilized plutonium canisters will contain approximately 2 tonnes (2000 kg; 2.2 tons) of mass, thereby forcing the use of heavy equipment to move the canisters.
- A gamma radiation barrier will be added to the immobilized plutonium canisters. The present concept is to add a radiation barrier that is greater than 1 Gy (100 rad) per hour at 1 m (3 ft) 30 years after fabrication.
- These canisters will then be sealed in casks and emplaced into drifts in a federal repository where they will be monitored for 100 years before the repository is sealed.

This immobilization process is shown conceptually in Figure 1.

In the electrometallurgical treatment (ET) variant, plutonium-rich residues are shipped to existing Argonne National Laboratory-West (ANL-W) facilities where the plutonium is converted to plutonium chloride, dissolved in a molten salt solution, sorbed on zeolites, and then immobilized in a glass-bonded zeolite (GBZ) waste form. The immobilization operations will be performed in facilities and equipment that are being prepared to treat Department of Energy (DOE)-owned spent fuels in the ANL-W hot cells. Costs are also estimated for a secondary case for simultaneous plutonium disposition and spent fuel treatment. The fission products from these fuels may contribute some radiation to the immobilization forms, but the ^{137}Cs from the Hanford capsules will provide most of the radiation field to create a radiation barrier.

1.1.1 Assumptions and Design Basis

Major assumptions used in the development of the ET variant include the following:

- The end-to-end immobilization facilities will receive plutonium as pits and in the various stabilized plutonium forms stored as a result of the Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 94-1 Program, and declared excess for national needs.
- The nominal feed of plutonium to the facility is 50 tonnes (56 tons).
- The campaign will take no more than 10 years to complete.

Additional assumptions and criteria for the ET options:

- Feed to the immobilization operations will be plutonium metal, oxides, and chlorides.
- The plutonium metal feed may contain metal impurities.
- All oxide feeds will be converted to the metal form with lithium reduction.
- The plutonium metal will be converted to the chloride form in an electrometallurgical cell.
- The immobilization medium for the plutonium will be glass-bonded zeolite.
- ^{137}Cs will provide the majority of the radiation barrier. Salt containing fission products from spent fuel treatment may be used to contribute to the radiation barrier.
- The plutonium chloride, $^{137}CsCl$, and TRU chlorides will be loaded into a zeolite matrix and hot pressed to produce GBZ.
- The Fuel Conditioning Facility (FCF) and the Fuel Manufacturing Facility (FMF) together with other appropriate facilities at ANL-W will be modified and enlarged if necessary to convert the plutonium as metal in pits to $PuCl_3$.
- Onsite storage will be provided at the Radioactive Scrap and Waste Facility (RSWF) at ANL-W pending shipment to the HLW repository.
- Blending of feed materials will be performed to minimize feed processing.
- Salt makeup comes from the Spent Fuel Treatment Program.

1.1.2 Feed Materials

This end-to-end immobilization variant (vitrification can-in-canister) will receive the following material forms which are expected to be declared excess to national programmatic needs of the United States:

- Pits
- Clean plutonium metal
- Impure plutonium metal
- Clean oxide
- Impure oxide
- Uranium plutonium oxide

- Plutonium alloys
- Alloy reactor fuels (unirradiated)
- Oxide reactor fuels (unirradiated)
- Oxide-like materials (residues)*
- Sand, slag, and crucibles (SS&C)*
- Halide salts*

To maintain a consistent feed downstream and to minimize overall processing, these feeds will be blended.

1.1.3 Physical Layout Location

Facilities at ANL-W available to support the electrometallurgical treatment variant are listed in Table 1.

1.2 First-Level Flow Diagram

The first-level flow diagram is shown in Figure 1. The plutonium feeds are in the forms resulting from stabilization and storage activities of the DNFSB 94-1 Recommendation Program. Plutonium metal will be removed from pits as the hydride, and the hydride will be converted to $PuCl_3$, which will be fed directly to the zeolite sorption step. Oxide storage forms will be fed to the lithium reduction step to convert them to metals. Metals, intermetallics, and alloys will be fed, along with the reduced metals, to the electrorefining cell where they will be converted to chlorides. Waste salt that contains transuranic (TRU) elements, UCl_3, and fission products from electrometallurgical treatment of spent nuclear fuel will also be fed to the electrorefiner. This waste salt provides a source of chloride for conversion of plutonium metal to $PuCl_3$ and a source of radiation to provide added proliferation resistance. Salt from the electrorefiner that contains $PuCl_3$, TRU element chlorides, and fission products is blended with $^{137}CsCl$ from cesium capsules. The blended salt is mixed with zeolite to ion-exchange and sorb the chlorides on the zeolite structure. This blended, free-flowing zeolite powder is then mixed with a suitable glass frit and hot pressed to make the final immobilization form.

1.2.1 Front-End Plutonium Processing—Disassembly and Conversion

The feed materials coming from DNFSB Recommendation 94-1 storage to the plutonium disposition facility will consist of metal (in pits or ingot form), oxides, unirradiated fuels, and other plutonium compounds. The processing required for each feed type are:

- **Pits.** The pit is first disassembled. Then the metal is removed from the pieces using hydriding. The hydride is then converted to a chloride and fed directly to GBZ fabrication.

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* These material categories are expected to be converted to impure oxide as part of the DNFSB recommended 94-1 stabilization program.

Table 1. Facilities to support the electrometallurgical treatment variant*

No.	Principal process facilities name*	Footprint m^2 (ft^2)
765	Fuel Conditioning Facility (FCF)	2,100 (22,600)
709	Safety Equipment Building (SEB)	230 (2,500)
785	Hot Fuel Examination Facility (HFEF)	1,700 (18,400)
775,776	Zero Power Physics Reactor (ZPPR) Facility	860 (9,300)
704	Fuel Manufacturing Facility (FMF)	440 (4,736)
	Support facilities	
752	Laboratory and Office Building (Includes Analytical Lab)	7,760 (83,500)
701	Security	540 (5,800)
771	Radioactive Scrap & Waste Facility	16,150 (173,800)
777	ZPPR Equipment bldg.	50 (500)
774	ZPPR Support Wing	2,720 (29,300)
792	ZPPR Mockup bldg.	280 (3,000)
784	ZPPR Materials Control bldg.	460 (4,900)
781	Material Handling Warehouse	2,450 (26,400)
782	Machine Shop Facility	510 (5,500)
783	Rigging Test Facility	220 (2,400)
787	Fuel Assembly and Storage	560 (6,000)
790	Interim Contaminated Equipment bldg.	240 (2,600)
791	Instrument & Maintenance Facility (IMF)	790 (8,500)
793	Components Maintenance Shop	410 (4,400)
793C	Contaminated Storage bldg.	210 (2,300)
794	Contaminated Equipment Storage Facility	460 (4,900)
796	Metal Stock Control bldg.	440 (4,700)
797	Outside Radioactive Storage Area	1,400 (15,000)
720	TREAT Facility	2300 (25,000)
721, 723, 724	TREAT Support Buildings	1300 (14,000)

* All facilities exist and are operational.

- **Metals and Alloys.** Plutonium metal in DNFSB Recommendation 94-1 residues can be fed directly into the electrorefiner for the ET process.
- **Metal Reactor Fuel.** The metal fuel could be in the form of a bundle and clad in zirconium or stainless steel. Hardware and cladding are removed, and the clad metal is stored for feed to the ET process.
- **Oxide Reactor Fuel.** The oxide fuel could be in the form of a bundle and clad in zirconium or stainless steel. Hardware is removed and the clad oxide is stored for feed to the ET process. No size reduction is necessary.
- **Oxides.** The oxides are stored for feed to the ET process.

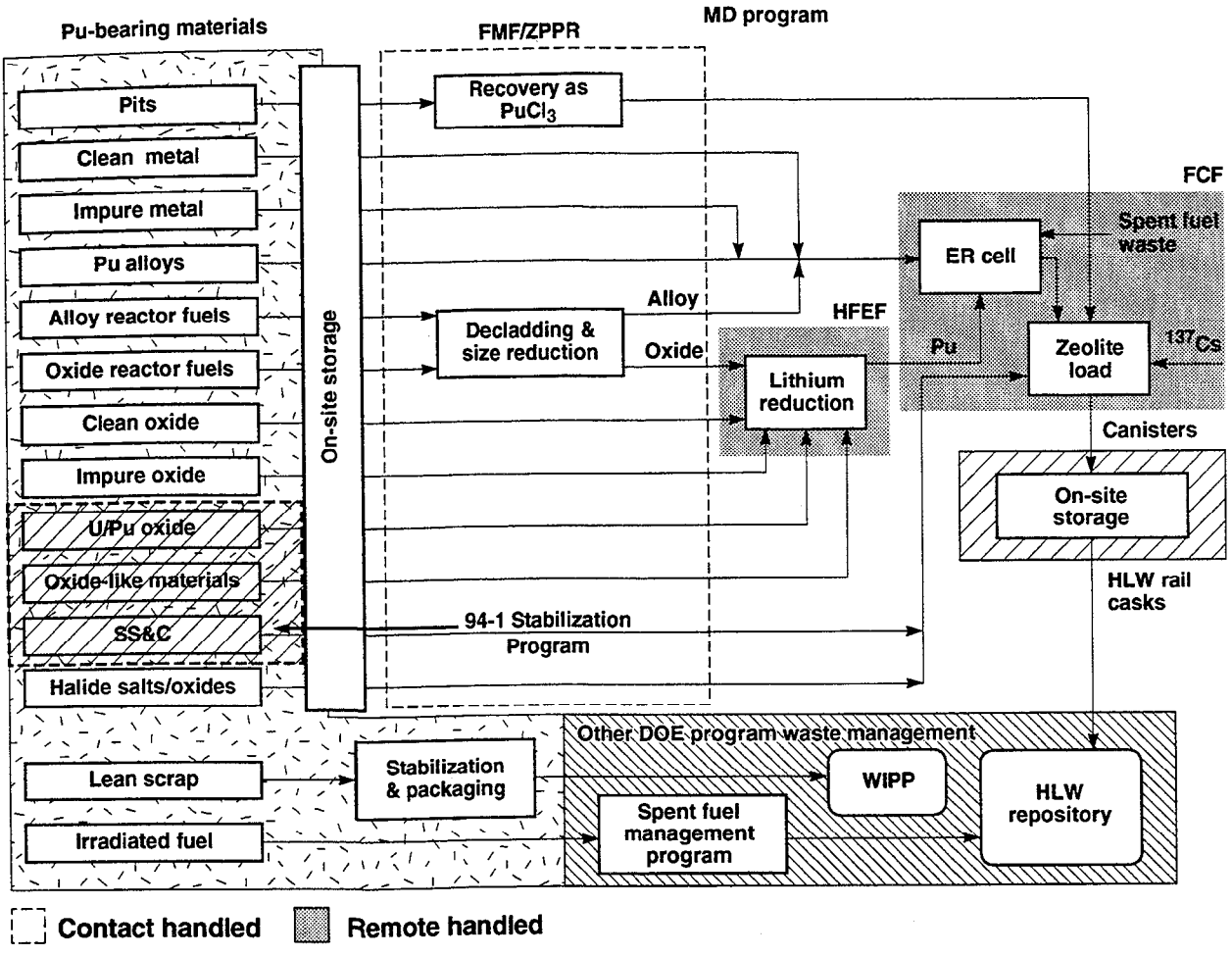

Figure 1. First-level flow diagram—end-to-end electrometallurgical treatment variant.

- **Blends.** Prior to feeding to downstream unit operation, all feeds will be blended to provide a more uniform downstream feed and to minimize the amount of processing required.

1.2.2 Back-End Processing—Glass-Bonded Zeolite Fabrication

Feed to the immobilization operations will be plutonium metal, oxides, and chlorides. Oxide feeds will be converted to metals in a lithium reduction step and then sent, along with metal feeds, to an electrorefining cell. The electrorefiner converts plutonium metal to chloride using an anodic dissolution process. Metal from pits would be converted to chlorides directly in front-end processing using a hydride/chloride process; the ARIES process would have to be modified to accommodate the conversion to chloride. Plutonium chlorides from the electrorefiner and front-end processing are blended with salt to which CsCl is added to provide the

radiation barrier. The blended salt is sorbed onto zeolite, and the zeolite is mixed with a suitable glass frit and hot pressed to make the monolithic mineral form (GBZ). The GBZ forms are loaded onto canisters and stored onsite until they can be transferred to a high-level waste repository for disposal.

1.3 Second-Level Flow Diagrams

The first-level flow diagram processing within the ET was expanded to two second-level flow diagrams. The two flow diagrams are designated as the front-end and back-end processing. The front-end processing covers the conversions of plutonium metal inputs to $PuCl_3$ and the preparation of various other plutonium forms for feeding to the ET back-end process, converting the plutonium chlorides into a GBZ form.

1.3.1 Front-end Plutonium Processing

The front-end processing (Figure 2) prepares the feeds for the ET process. The following are descriptions for the unit operations.

DC-01 Truck and CRT Unloading. Material shipments will be delivered to a truck and container restraint transport unloading dock where the delivery-safe secure trailer/transport (SST) will be washed and smear-checked. The packaged plutonium cargo will then be unloaded. Initial assessments of radiation levels and container breaches are made during the unloading process to ensure a safe configuration for temporary storage while awaiting receiving and inspection. Shipping papers are checked, tamper indicating devices (TIDs) are inspected, and neutron counts are made on the packages. Emptied container restraint transports shipping containers are inspected, decontaminated, if necessary, and prepared for return.

DC-02 Receiving. Receiving includes material confirmation, accountability, safety, and inventory measurements. The plutonium cargo is unpacked from the shipping containers and repackaged in suitable storage containers in concert with the measurement activities. The repackaged material is placed in the storage vault where it will await processing. Contaminated containers are handled in a decontamination station where the material is retrieved and repackaged. The containers are decontaminated.

DC-03 Gas Sampling. Pits that have potential contamination of the material are checked. Contaminated pits are sent to Special Recovery (DC-04), while uncontaminated pits are sent to Pit Disassembly (DC-05).

DC-04 Special Recovery. Contaminated pits are disassembled and the resultant parts are cleaned. Plutonium-bearing parts are separated from the balance of the material. This operation consists of the following glove box operations: disassembly, tool storage, bakeout, nondestructive analysis (NDA), and subcomponent packaging.

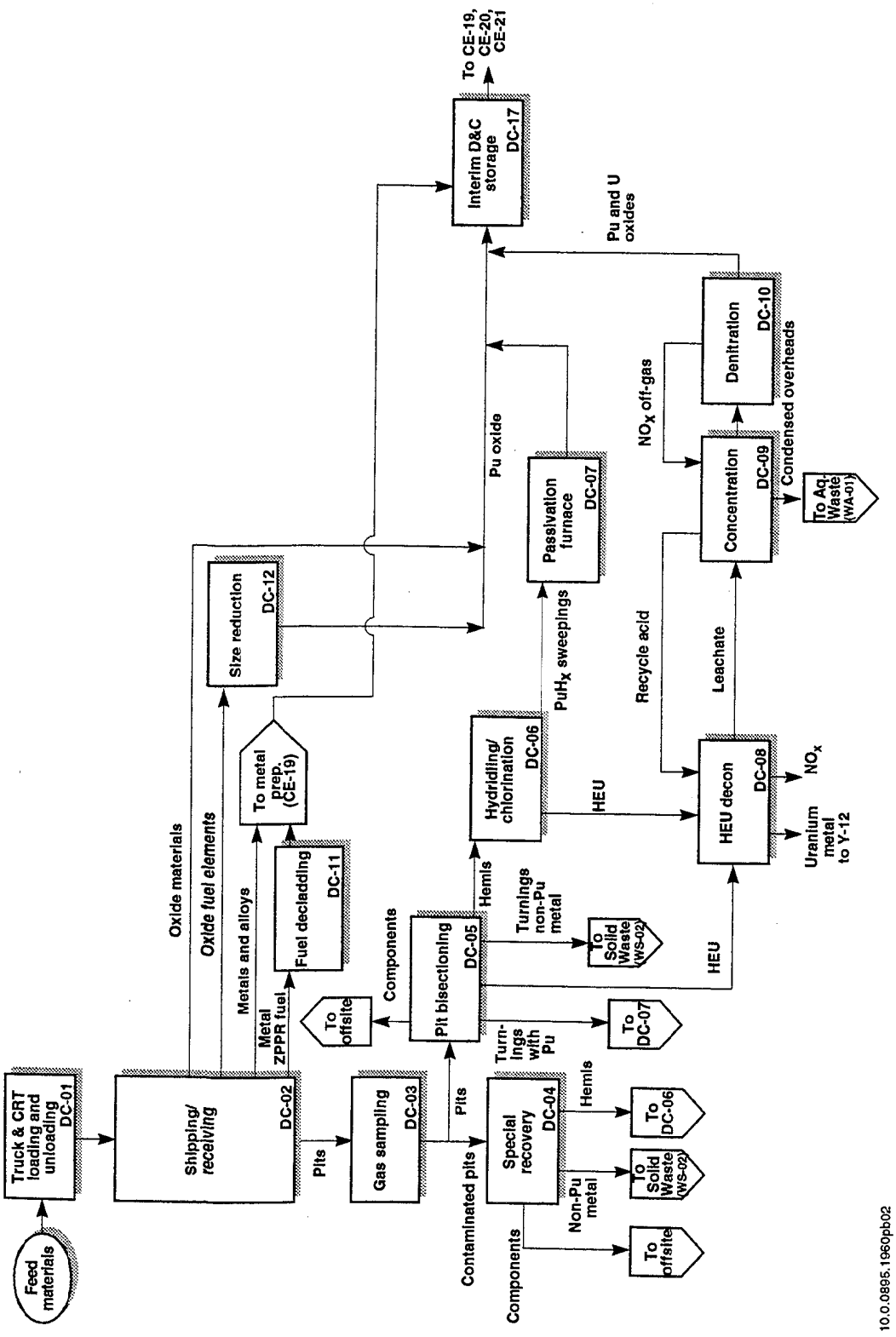

Figure 2. Second-level flow diagram—ET front-end plutonium processing.

DC-05 Pit Bisectioning. Pits are bisected to allow for plutonium removal using hydriding. This operation will consist of one work station for receiving and one work station for the pit bisector.

DC-06 Hydriding/Chlorination. Plutonium is reclaimed from the bisected parts and converted to chloride. The hydride process removes the plutonium from the parts. The chlorination step converts the hydride to a chloride. This operation consists of an accountability work station and a work station for the hydride/chlorination unit. The $PuCl_3$ product is fed to the ET process without further treatment.

DC-07 Passivation Furnace. This step converts any hydride that might be in the box sweepings to oxide.

DC-08 Decontamination. HEU having economic value will be decontaminated with an acid bath, rinsed, and packaged for shipment to a processing facility.

DC-09 Concentration. Plutonium carried into the leachate from the Oy decontamination process (DC-08) will be concentrated, and the reclaimed acid will be returned to the Oy decontamination process.

DC-10 Denitration. The plutonium-bearing concentrate from Concentration (DC-09) will be denitrated to remove NO_x from the concentrate, resulting in plutonium and uranium oxides.

DC-11 Fuel Decladding. The major feed to this operation is zero power physics reactor (ZPPR) fuel. ZPPR fuel is stainless steel clad metal fuel in the form of thin plates. The decladding operation will employ a planning operation where one side of the cladding will be removed. The fuel element will then be sent through a device that will pull the stainless steel hull away from the metal fuel. The primary waste generated in this operation will be the stainless steel cladding hulls and spent tool bits. The glove box for this operation has a receiving workstation, a planing workstation, and a dehulling workstation.

DC-12 Size Reduction. The lithium reduction step reduces dense PuO_2 in pieces as large as a centimeter. If the pieces are larger they will have to be size reduced.

DC-17 Interim Disassembly and Conversion (D&C) Storage. The interim D&C storage is a vault that stores the pretreated product in critically safe geometry until they are processed by the back end.

1.3.2 Back-End Processing

The plutonium bearing metals, oxides, and chlorides are converted to chlorides in solution in molten LiCl-KCl eutectic salt. This salt is sorbed in zeolite, and the zeolite is mixed with a suitable glass frit and hot pressed to make a monolithic mineral form called glass-bonded zeolite (GBZ). Figure 3 shows the second-level flow diagram for these operations. The ET back-end process steps are described below.

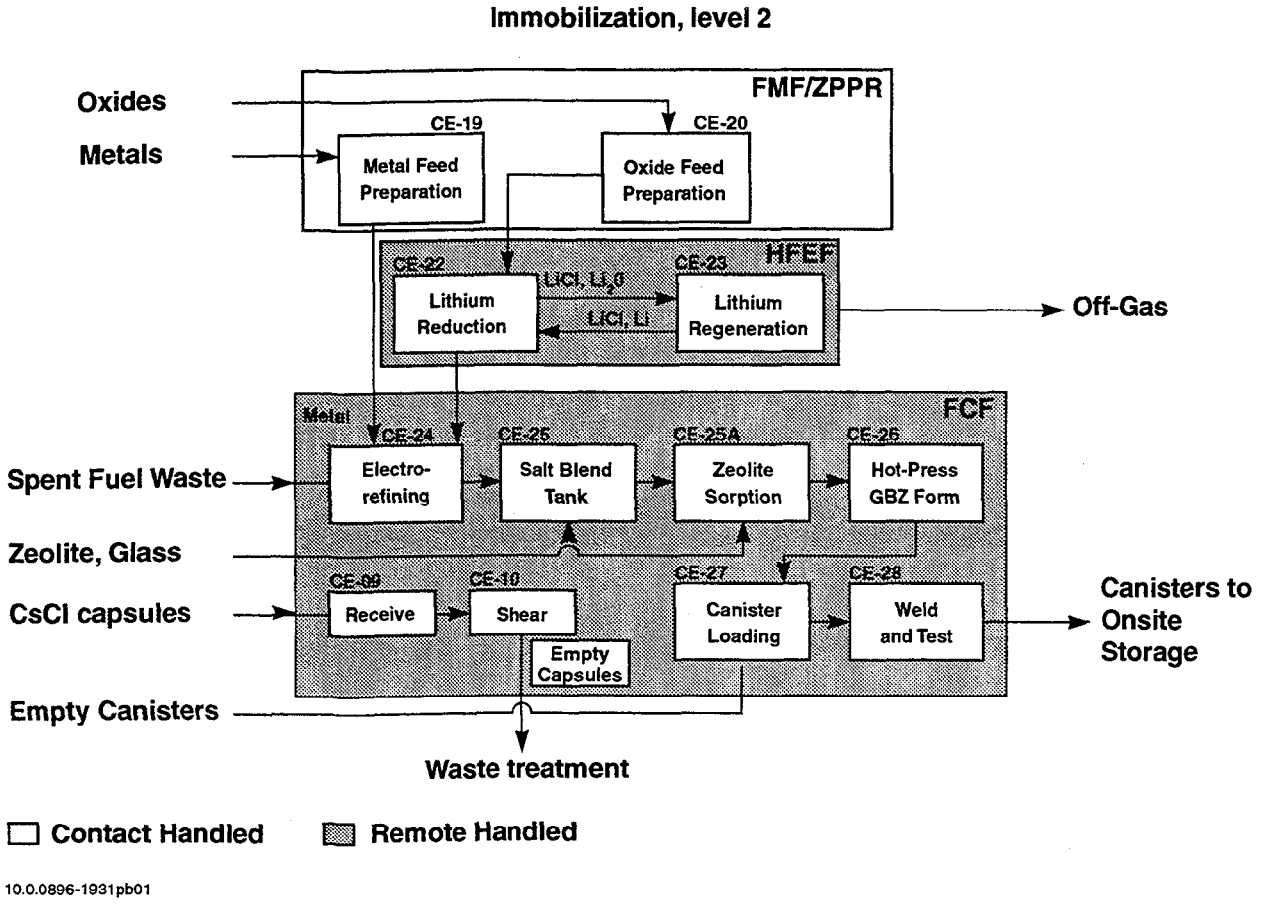

Figure 3. Second-level flow diagram—ET back-end immobilization processing.

CE-19 Metal Feed Preparation. Metals, intermetallics, and alloys are removed from the storage can, and any cladding that may be present is breached. The metal pieces are reduced in size sufficiently to allow them to be placed in the anode baskets of the electrorefiner. These anode baskets are then transferred to the electrorefiner (Step CE-24).

CE-20 Oxide Feed Preparation. This preparation is based on known composition of the stored material.

- Oxides that are rich in PuO_2 and that contain no materials harmful to the process are loaded into reduction baskets and placed into the lithium reduction, Step CE-22.
- Oxides that are lean in PuO_2, such as ash or contaminated firebricks, are crushed and subjected to a magnesium-chloride extraction. The extraction salt that contains the solubilized plutonium is fed to lithium reduction, Step CE-22.

- Any residue oxides from salt extraction (CE-25) that contain significant amounts of plutonium are fed to Zeolite Sorption, Step CE-25A, to be mixed with the other oxides destined for the immobilization form; they form part of the glass matrix.

CE-22 Lithium Reduction. The oxides are transferred into the hot cell, where they are placed in reduction containers that are placed into LiCl-Li metal bath inside the reduction vessel. Agitation is started and the molten TRU oxides are reduced to metals which remain in the containers. The resulting Li_2O dissolves in the LiCl salt and remains below saturation concentration. The reduced metals in their containers are removed from the reduction vessel, and the molten salt, containing dissolved Li_2O, is transferred (through a heated transfer line) to the lithium regeneration step (Step CE-23).

CE-23 Lithium Regeneration. The lithium regeneration cell operates by electrolytically decomposing the Li_2O in the presence of molten LiCl. Oxygen is evolved at an inert anode, and lithium metal is deposited at a steel cathode, where it collects as a liquid lithium pool. The oxygen is swept out of the cell with an inert-gas sparge stream, and the gas is vented through high-efficiency particulate air (HEPA) filters to the environment. The lithium regeneration cell will be designed to operate continuously or semi-continuously, depending on the outcome of R&D and demonstration testing. The Li_2O-laden LiCl is introduced at the high-oxygen end of the cell, and the purified LiCl and lithium metal are removed (probably by gravity flow) from the other end of the cell. Lag storage may be required at both ends of the cell to maintain continuous or semi-continuous operation.

CE-24 Electrorefining. The metal product removed from the lithium reduction step (Step CE-22) is transferred, in its container, to the electrorefiner. The electrorefiner uses as electrolyte the LiCl-KCl eutectic that contains a few mol% actinide chlorides, principally UCl_3; it operates at about 500°C (900°F). In the electrorefiner, TRU metals are converted to chlorides, such as $PuCl_3$, that are soluble in the molten LiCl-KCl. The electrochemical chlorination step operates by converting plutonium metal to Pu^{3+} ions at the anode while reducing UCl_3 to uranium metal at the cathode. The initial loading of uranium ions is introduced with the spent fuel waste salt. Additional U^{3+} ions could be generated by the addition of uranium metal and a suitable chlorinating agent, such as $FeCl_2$, but the waste salt from processing spent fuel could contain sufficient UCl_3 to chlorinate the plutonium while depositing uranium metal. When the concentration of $PuCl_3$ (and other TRU trichlorides) reaches a level of about 6 to 10 wt%, a fraction of the electrolyte salt is transferred to the salt blend step (Step CE-25). This transferred salt is replaced with makeup salt from the spent fuel treatment process, having a fresh loading of UCl_3. After the plutonium is anodically dissolved out of the metal-product container, the container is removed from the electrorefiner for recycle to the lithium reduction step (Step CE-22). Residual metals (other than the TRU metals) may need to be removed from the containers prior to their recycle, and after several cycles (perhaps 20) the containers must be discarded as waste.

CE-25 Salt Blend Tank. The salt blend tank is a heated tank with a mixing agitator that functions to mix the salt streams, including the electrorefiner salt that contains

most of the plutonium as $PuCl_3$, as well as other TRU element chlorides and fission products from treatment of spent fuel; $PuCl_3$ from pits (Step DC-06); cesium and barium chlorides from the cesium capsules stored at Hanford. These salts are thoroughly mixed and heated to make them homogeneous and at the proper temperature for loading onto the zeolite. The salt mixture is then transferred to the zeolite sorption furnace.

CE-25A Zeolite Sorption. The zeolite sorption step consists of hot-mixing anhydrous zeolite with the chloride salts from the blend tank. The chloride feeds are inserted into a blending furnace that contains the anhydrous zeolite. The zeolite sorbs all of the molten salt, leaving a dry zeolite powder. The loaded zeolite is then blended with an appropriate amount and composition of bonding glass frit. This powder mixture is now ready for the hot-pressing step to make the monolithic GBZ immobilization form.

CE-26 Hot Press GBZ Form. The hot pressing operation may be uniaxial pressing or hot isostatic pressing, depending on the outcome of the R&D program. But, in either case, the dry zeolite/glass powder is loaded into either a mold (for uniaxial pressing) or a bellows (for hot isostatic pressing), and hot pressed. The final immobilization form will be a large "hockey puck" style glass-ceramic structure. The optimum size and shape of these structures will be determined as part of the R&D program. The "hockey pucks" are transferred to the canister loading step, CE-27.

CE-27 Canister Loading. Here, the GBZ "hockey pucks" are loaded into canisters in preparation for sealing, testing, and placement into interim storage. The canister materials will be selected, based on the large database of canister material behavior in geological environments.

CE-28 New Canister Weld and Test. After the GBZ "hockey pucks" have been loaded into the canister, the head of the canister will then be welded to the body of the canister and the weld tested. Upon completion of the test, the canister will be placed in temporary storage.

CE-09 Cs Capsule Receiving. The cesium capsule receiving step must be capable of receiving, handling, and storing extremely radioactive sources. The storage capacity of this receiving operation must be sufficient to handle a six-month inventory of capsules.

CE-10 Cs Capsule Shear. The cesium capsule shearing step will cut the capsules open, recover the contents of the capsules, transfer the contents to the blend tank, CE-25, decontaminate the empty capsules (e.g., a simple molten salt wash), and send them to waste treatment. This step will be performed in the FCF argon cell. The capsules are not opened in air due to the risk of pyrophoricity. In this option, the waste treatment may be melting the empty capsules with the metal waste form as part of the spent fuel treatment.

1.4 Facilities

ANL-W Site. Figure 4 shows the overall plot plan for the ANL-W site. Glove box operations and some storage will be carried out in the ZPPR/FMF complex. Both FCF and HFEF are used primarily for processes requiring heavily shielded hot cells. The FMF and ZPPR are secure facilities that are used for operations that can be performed in lightly shielded glove boxes. The layouts of FMF and ZPPR are shown in Figures 5 and 6; the layouts of FCF and HFEF with the ET immobilization equipment are shown in Figures 7 and 8. The RSWF facility will be used for onsite storage of the ET waste canisters.

Facility Sizing. Floor spaces of the existing ANL-W facilities that are proposed for the electrometallurgical treatment immobilization variant are provided in Table 1.

The total floor area required for the front-end plutonium processing function is approximately 1115 sq m (12,000 sq ft) for plutonium processing, 1395 sq m (15,000 sq ft) for direct plutonium processing support, and 3995 sq m (43,000 sq ft) for auxiliary support functions. The use of the available space in ANL-W and requirements for new space for this function is being evaluated.

Balance of Plant Facilities. These facilities include personnel offices, a fire station, minor medical services, instrumentation and maintenance shops, an extensive machine shop, drafting facilities, a cafeteria, an NDA laboratory, sewage and industrial waste treatment, water supply and distribution, electricity supply and distribution, and onsite transportation services.

1.5 Cross-Cutting Technologies

1.5.1 Transportation

Overview. The transportation and packaging function provides the means to transport the surplus fissile material and other radioactive material from the various DOE facilities to various other processing facilities to accomplish the immobilized disposal option. The transport and package requirements for each transportation leg and transportation or packaging regulatory requirements are presented below.

Regulations. Transportation of plutonium and associated wastes will be subject to government regulations such as those of the Nuclear Regulatory Commission (NRC), the Department of Transportation (DOT), and the Department of Energy (DOE). Different regulations may apply for different portions of the immobilized end-to-end flow depending upon which agency has authoritative control. The FMDP assumes that any new facility that is required to accomplish the immobilization option will be licensed by the Nuclear Regulatory Commission. For any currently existing facility, it is assumed that the DNFSB will be the reviewing agency. For scheduling purposes, the time required is assumed to be the same for the NRC and the DNFSB.

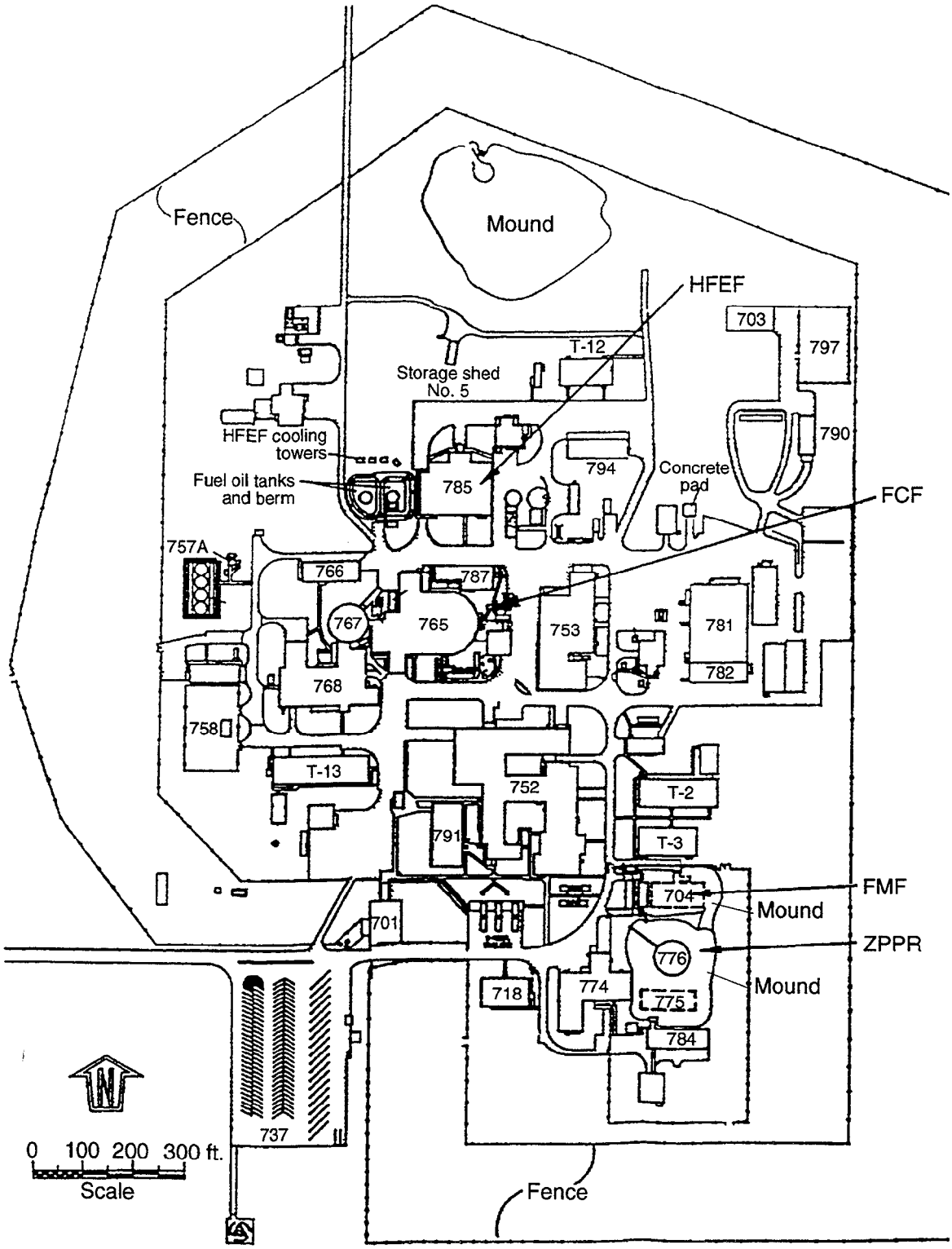

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Figure 4. Detailed layout of the ANL-W site.

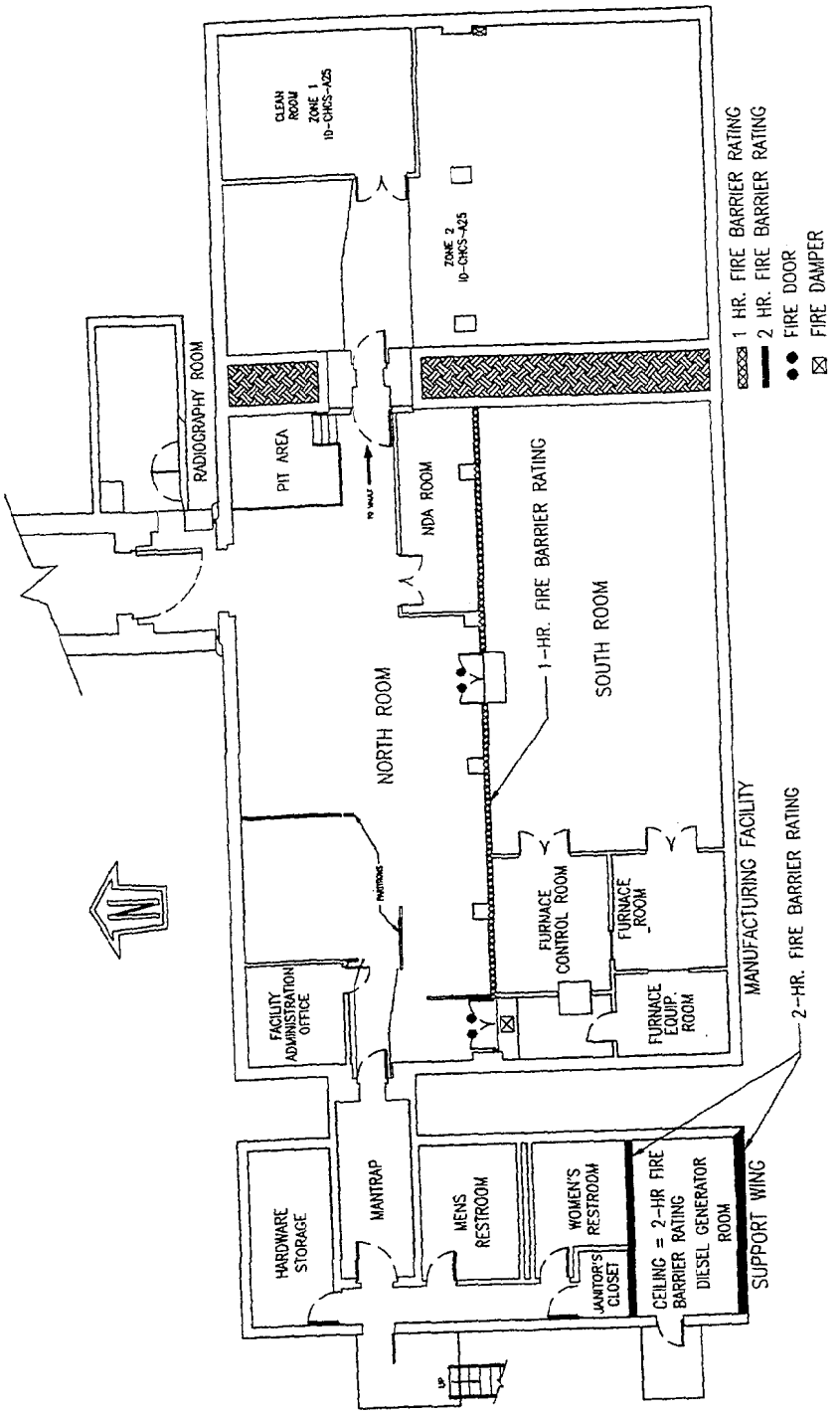

Figure 5. Building 704 FMF floor plan.

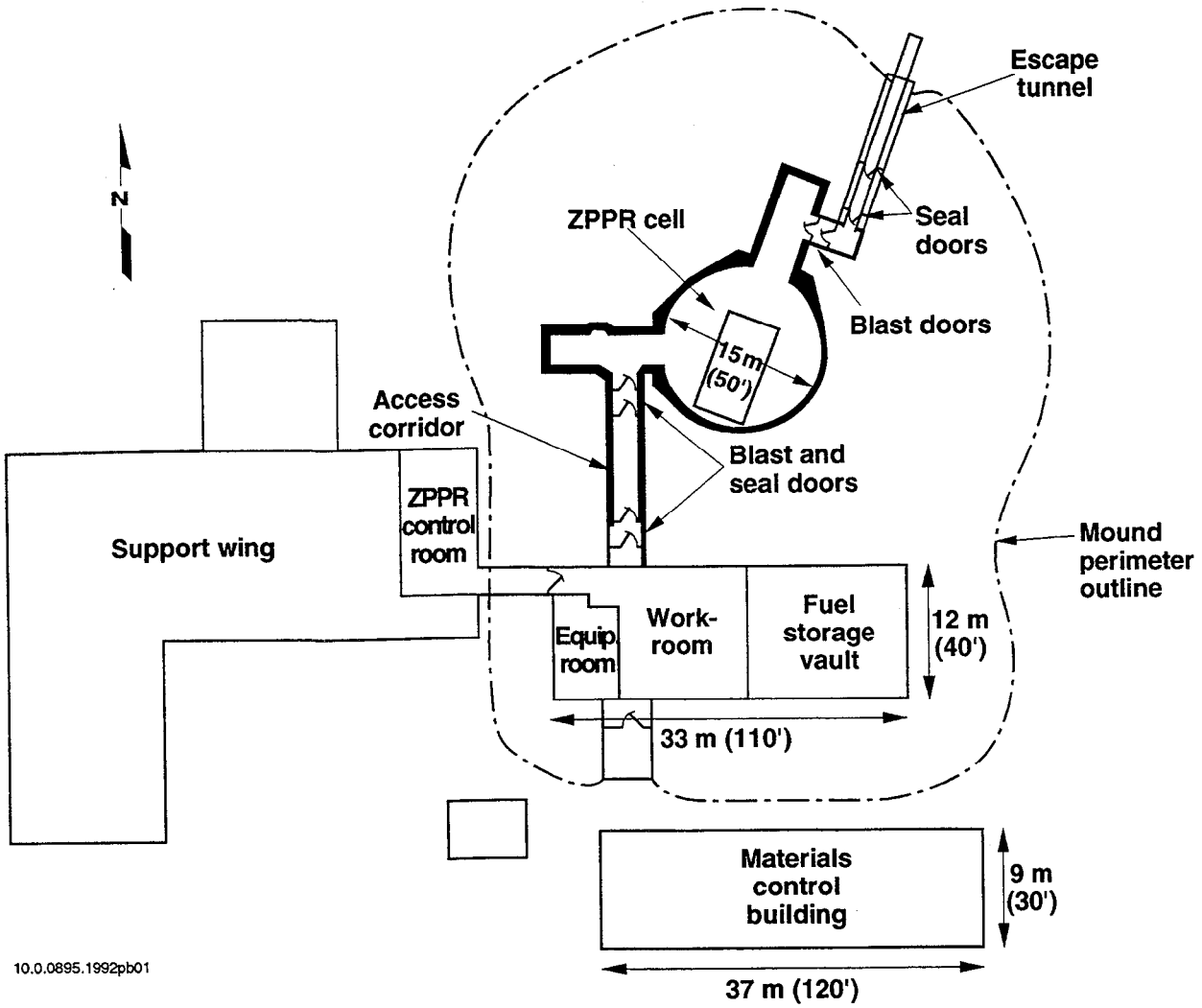

Figure 6. ZPPR floor plan.

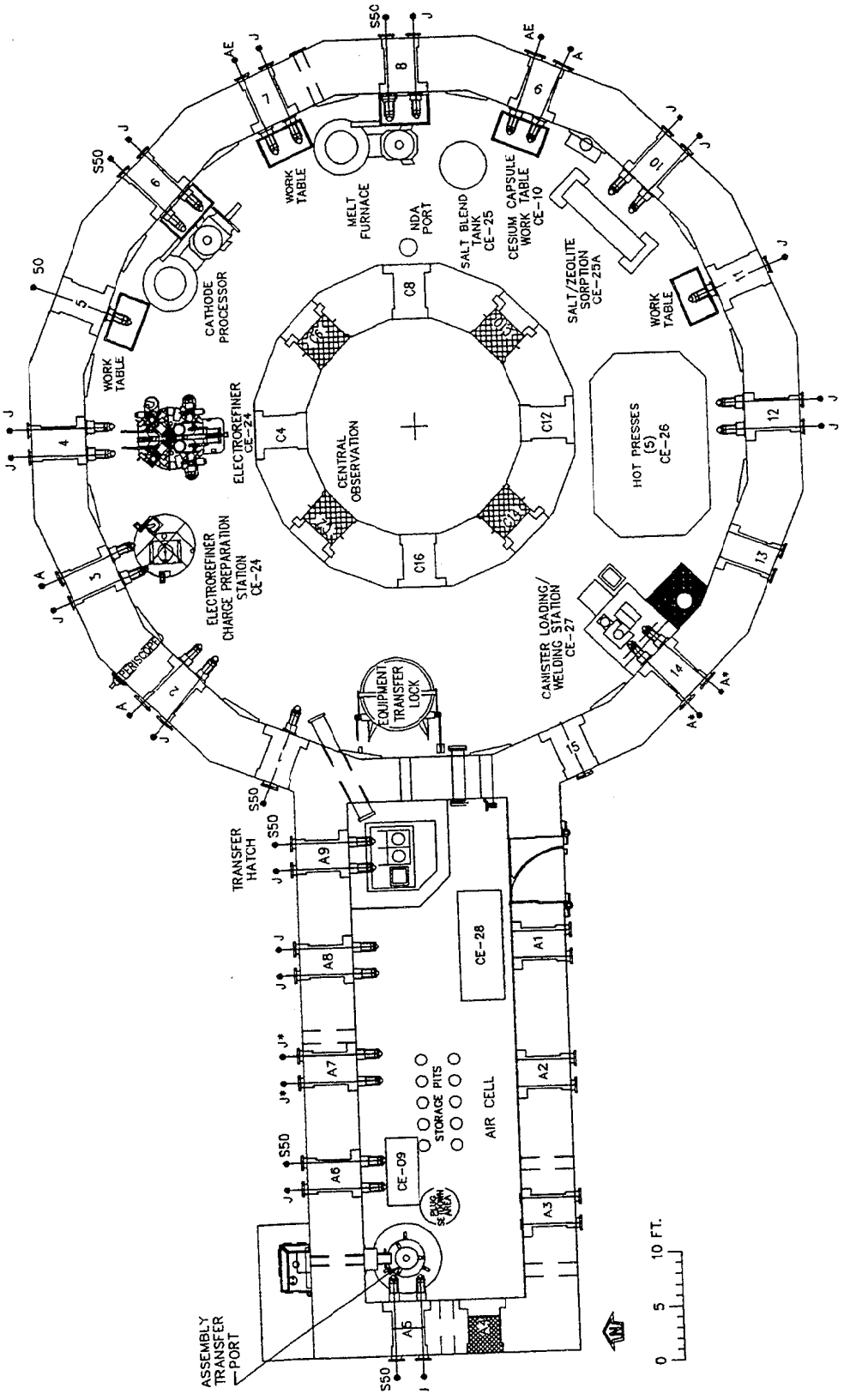

Figure 7. Plan view of the FCF air and argon cells, showing layout of plutonium immobilization and interfacing spent fuel treatment equipment.

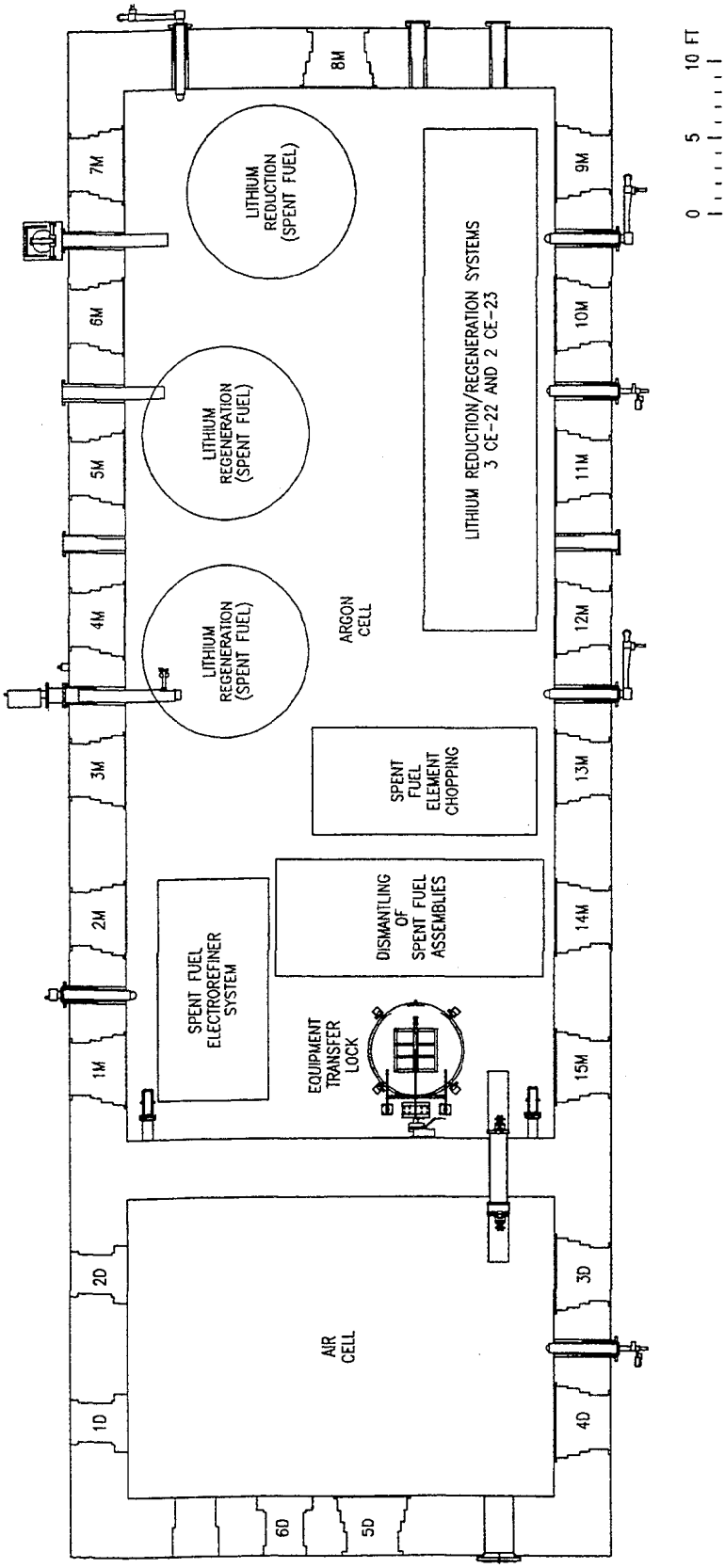

Figure 8. HFEF floor plan.

The NRC regulation (10 CFR 71) establishes the requirements for packaging, preparation for shipment, and transportation of licensed material. This regulation also defines the procedures and standards for obtaining NRC approval of packaging and shipping procedures for fissile material and Type B quantities of other licensed materials. (A quantity of weapons-grade plutonium in excess of ~25 mg constitutes a Type B quantity per 10 CFR 71). By reference, 10 CFR 71 incorporates DOT regulation 49 CFR 170-189. Whenever possible, the DOE transports radioactive materials under NRC regulations. However, for the purpose of national security, 49 CFR 173.7 (b) allows the DOE to ship radioactive material under escort by personnel designated by the DOE, thus waiving the DOT regulations in 49 CFR 170-189. This exemption, however, is rarely used, and its use is not anticipated for FMDP.

There are different requirements for the transportation of nuclear materials depending upon if the movement of materials is considered onsite (intrasite) versus offsite (intersite). Currently, there are no federal regulations governing onsite transport of hazardous materials. For DOE facilities, onsite and offsite transportation requirements are defined in DOE Order 460.1. Onsite is any area within the boundaries of a DOE site or facility that is fenced or otherwise accessed-controlled and offsite is any area within or outside of a DOE site to which the public has free and uncontrolled access.

Transportation System. The transportation system is described below and shown graphically in Figure 9. There are three intersite transportation segments for the end-to-end ET immobilization option. Intrasite transportation occurs at the DOE origin facilities, Westinghouse Hanford, ANL-W site where the conversion/stabilization facility is co-located with the ET immobilization facility, and the HLW repository.

Intersite Transportation Segment #1—During this segment, fissile material located at various DOE facilities is transported to the ANL-W (Idaho) onsite temporary storage. The material requiring transport includes: pits, clean metals, impure metals, impure oxide, clean oxide, alloys, compounds, rich scrap, miscellaneous material, and reactor fuel.

Package Description. The pits under the FMDP will be stored and transported in the Model FL or the AT-400A container. The various pits can utilize these containers by using different internal fittings.

The other plutonium material is assumed to be at onsite storage at the various DOE facilities. The material and package is assumed to meet *The Criteria for Safe Storage of Plutonium Metals and Oxides* stated in the DOE standard *DOE-STD-3013-96*, July 1996. This criteria states that all plutonium metal and oxides (excluding pits) over 50 wt% plutonium shall be stored in a storage container that includes a minimum of two nested hermetically sealed containers to serve as barriers to isolate the stored materials from the environment and to prevent contamination release.

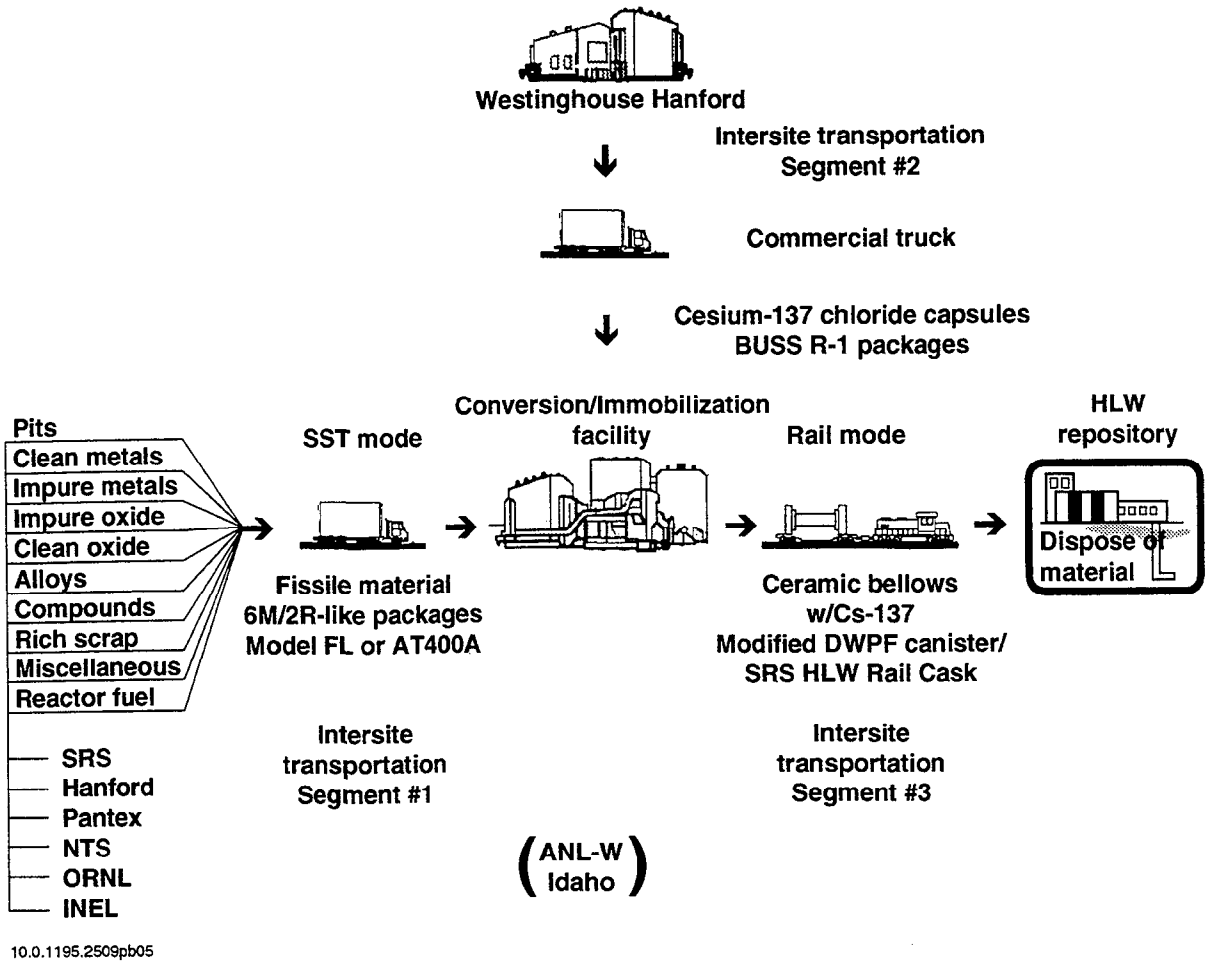

Figure 9. Simplified flow chart showing transportation segments.

For transporting the plutonium material (non-pit), the storage container would be loaded into another shipping container, a 6M/2R-like which could provide double containment if required. Two 6M/2R-like package designs that could incorporate the storage container are the SAFREG and the Chalfant. These specific designs would require modifications to ensure that the package criteria stated in DOE-STD 3013 are met. Further modifications would be required to ensure: 1) the packaging configuration incorporates the storage container, 2) analysis/testing is performed to show the abnormal and normal accident scenarios, and 3) the Safety Analysis Report is modified to show the changes.

Unirradiated reactor fuel forms to be shipped from the various DOE sites in this segment consist of unirradiated pellets, pins, and fuel assemblies. This material can be shipped either in these forms in an NRC certified package like the model number MO-1 (Certificate number 9069) or as pellets in a 6M/2R-like package. In either case, the material shipments will consist of Category I quantities with the requirement for safe secure trailer/transport. A review of these variants shows that shipment as pellets greatly reduces the number of individual shipments required if the MO-1 package is

used. Additionally, shipment as pellets in a 6M/2R-like container by safe secure trailer/transport results in a further reduction of individual shipments.

As a result the 6M/2R-like package is the preferred option for unirradiated reactor fuel shipment, and no distinction will be made between reactor fuel and other non-pit plutonium material when considering intersite transportation segment #1.

Shipment Information. A 10-year FMDP shipment campaign has been assumed with a total quantity of 50 tonnes (56 tons). The total package and shipment quantities for intersite transportation segment #1 are shown in Table 2. Table 2 summarizes shipment information that was applied to all the FMDP variants in order to provide an even comparison among variants. The amount of detail that is provided in Table 2 has been limited due to classification issues.

Transportation Segment #2—During this segment, ^{137}Cs chloride capsules are transported from Hanford, located at Richland, Washington and are taken to the ET facility at ANL-W in Idaho. The CsCl capsules are transported as a Type B quantity of special form radioactive materials. The BUSS R-1 packaging (NRC certificate no. 9511), was developed for shipment of the Hanford capsules and is routinely used for shipping the capsules. The BUSS R-1 has the capacity to hold up to 16 capsules but is limited due to heat output of the material. The $^{137}CsCl$ capsules can be transported by commercial truck or rail carrier licensed for radioactive material transport. This information is summarized in Table 3.

Transportation Segment #3—During this segment, GBZ "hockey pucks" loaded with 5% weapons grade plutonium are transported from ANL-W to the HLW repository.

Package Description. GBZ "hockey pucks" containing 5% weapons-grade plutonium and ^{137}Cs will be placed in the ANL-W HLW canister. The detailed design of the ANL-W canister has not been developed or designed. This canister would need to be approved for acceptance in the HLW repository and certified for transport.

Table 2. Intersite Transportation Segment #1.

Average material/ storage container	Quantity Pu/ yr	Quantity Pu/ campaign	# packages/year (6M/2R-like + pit containers)	Total # packages (6M/2R-like + pit containers)	SST shipments/ yr	SST shipments/ campaign
4.5 kg (10 lbs)	5000 kg (11,000 lbs)	50,000 kg (110,000 lbs)	3,100	31,000	110	1,100

Table 3. Parameters for Intersite Transportation Segment #2.

Data	^{137}CsCl shipment
Packaging	
Type	BUSS R-1
Certifying agency	NRC/DOE
Material weight/capsule	0.471 kg (1 lb)
Capsules per packaging	10
Average shipping volumes	
Quantity material/yr	47 kg (100 lbs) Cs
Capsules/yr	100
Capsules/life of project	1000
Shipments/yr	10
Shipments/life of project	100
Routing	
Mode of transport	commercial rail or truck*

* Above numbers calculated using the preferred mode of rail.

Immobilized Package Description. Eight of the ANL-W canisters are placed in a canister with dimensions similar to the Defense Waste Processing Facility (DWPF) high-level waste canister. The SRS DWPF canister design, or a similar container, is expected to provide the primary containment boundary for transport. Figure 10 shows the configuration to be used for all vitrification options.

The additional packaging component required is a transportation cask which should also provide the radiation shielding necessary for shipping the DWPF canisters to a HLW repository. The SRS has completed a conceptual design study for a rail shipping cask for DWPF canisters. This HLW cask, shown in Figure 11, will hold five DWPF canisters, each of which contains eight ANL-W canisters. After the SRS HLW rail cask design is completed, certified, and approved by the NRC for DWPF canister transport, it can be certified and approved for shipping the immobilized plutonium forms in the ANL-W canister to the HLW repository.

The ANL-W HLW form is described in Table 4.

Shipment Information. Table 5 details the packaging requirements and mode of transport for the immobilized zeolite material.

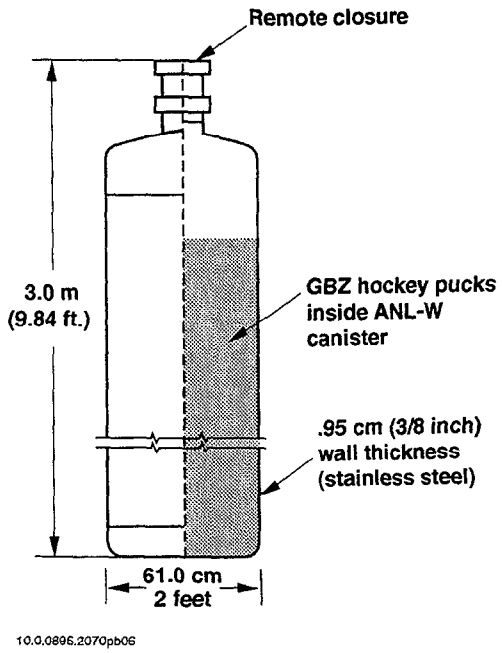

Figure 10. Modified DWPF canister containing ANL-W waste forms.

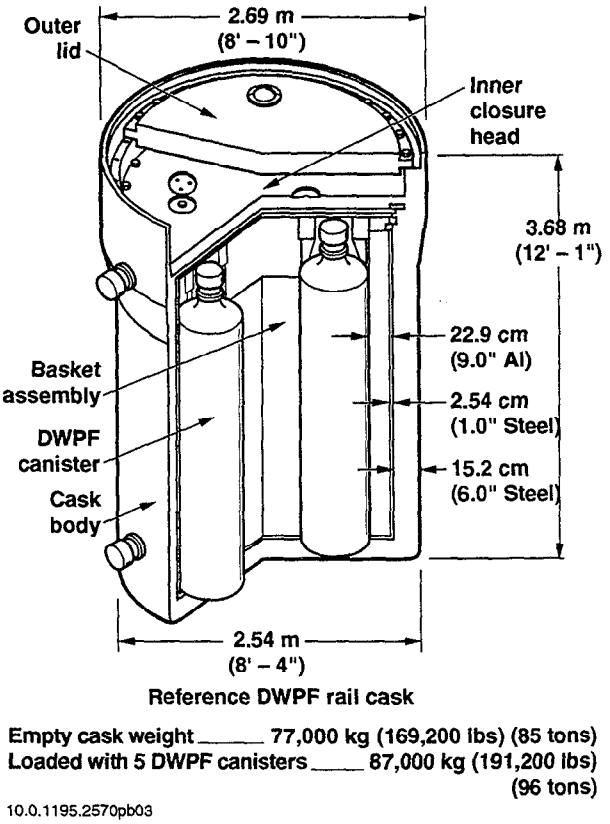

Figure 11. SRS HLW rail cask.

Table 4. ANL-W HLW waste form.

GBZ density	2.6 gm/cm^3 (162 lbs/ft^3)
Dimensions of one form (hockey puck)	
Diameter	22 cm (8.75 in.)
Height	10 cm (4.0 in.)
Weight	10 kg (22 lbs)
Dimension of ANL HLW canister	
Material	304 SS
Outside diameter	23 cm (9.0 in.)
Wall thickness	.19 cm (0.075 in.)
Overall height (including lifting attachment)	144 cm (56.5 in.)
Weight of ET waste forms (13 hockey pucks)	130 kg (286 lbs)
Weight of weapons-grade plutonium	6.5 kg (14 lbs)

Table 5. Parameters for Intersite Transportation Segment #3.

Data	Glass-bonded zeolite
Packaging	
Type	8 ANL-W HLW canisters in modified DWPF canister
Certifying agency	not currently certified
Material weight /DWPF canister	1040 kg (2,288 lbs) of GBZ/DWPF canister
DWPF canisters/rail cask	5
Wt Pu/DWPF canister	52 kg (114 lbs)
Average shipping volumes	
Quantity material/yr	5000 kg/yr (11,000 lbs/yr)
HLW rail cask shipments/yr	19 SRS HLW rail casks
No. of shipments/campaign	192 SRS HLW rail casks
DWPF canisters for life of project	962
Routing	
Mode of transport	commercial rail or truck

1.5.2 Domestic Safeguards

The FMDP has established two major safeguards and security (S&S) criteria. Resistance to theft or diversion by unauthorized parties (Criteria 1, domestic) and resistance to retrieval, extraction, and reuse by the host nation (Criteria 2, international) consider domestic and international perspectives based on two important factors: the "threat" addressed by these criteria, and the "regimes" that exist to address these threats.

The primary purposes of FMDP domestic safeguards and security is to assure nonproliferation of fissile material and classified information, along with instilling public and international confidence in those actions. Domestic safeguards and security is composed of two subsystems, nuclear materials control and accounting and the physical protection of fissile material and nuclear weapons components against threats of diversion and theft, along with that of radiological and toxicological sabotage. Domestic safeguards and security primarily address unauthorized actions perpetrated by individuals and/or subnational groups (insiders or outsiders).

The detection and prevention of an unauthorized access or removal attempt (e.g., theft or diversion) depends on the levels of safeguards and physical protection at the facility. In general, safeguards are more easily applied and more readily verified when materials are in the form of discrete, uniquely identifiable items, as opposed to difficult to measure materials in bulk form, as may be found with chemical processing activities. The DOE, and the NRC, have established requirements for domestic safeguards and security. In the U.S., both the DOE and NRC have specific orders or regulations that

identify physical protection, and material control and accountancy. There are measures that must be followed, as determined and negotiated based upon the category and attractiveness of the fissile material.

The responsibility of the domestic regime is to prevent unauthorized access to its material either by individuals or groups within its own weapons complex (such as disgruntled workers) or by national or international terrorist groups, criminal organizations, etc.

The domestic threats can be condensed as: *theft* (e.g., unauthorized removal of material by an individual or group outside of the host nations weapons complex), *diversion* (e.g., unauthorized removal of material by a member of the host nations own weapons complex), *retrieval* (unauthorized access by outside individuals or groups after final disposition), and *conversion* (the conversion of retrieved material into weapons usable form).

1.5.3 International Safeguards and Nonproliferation

The responsibility of the international safeguards regime is to prevent the host country from diverting , retrieving, or converting material that has been declared surplus. Thus, the context of safeguards and security should be viewed not only from the U.S. DOE perspective, but from the perspective of another country looking at the U.S.

The international threats can be condensed as: *diversion* (unauthorized removal of material by the host nation itself in violation of the international regime before final disposition has taken place), *retrieval* (unauthorized access by the host nation in violation of the international regime after final disposition), and *conversion* (the conversion of retrieved material into weapons usable form).

This area includes FMDP activities which may be affected by international or bilateral agreements which may be subject to the International Atomic Energy Agency (IAEA). International safeguards are composed of two subsystems, nuclear materials accountancy and materials containment and surveillance, which are required to satisfy international inspection agreements. International safeguards and security is focused on the independent verification of material use through material accountancy programs, and containment and surveillance systems.

The IAEA has established safeguards criteria for the material control and accountability, and the containment and surveillance of fissile material. The requirements in this area are derived from IAEA statutes and informational circulars. The IAEA, in concert with member states (most notably the U.S.) has also developed recommendations for states to develop appropriate domestic security measures, but they are recommendations, and not audited requirements. The safeguards criteria and security recommendations are typically based on practices followed in the U.S. and agreed upon by the IAEA member states.

Domestically, the DOE and NRC are the safeguards and security policing agencies (depending upon jurisdiction). However, internationally there is no direct police organization for domestic safeguards and security. Specifically, the International Atomic Energy Agency has no jurisdiction or obligation to oversee the measures taken by a state (or host nation) to address unauthorized access to special nuclear material (Criteria 1). In this variant, it is assumed that all facilities except the plutonium processing facility will be subject to IAEA safeguards. Depending on agreements that would be made, between the U.S. and the IAEA, part of the plutonium processing facility may, or may not, come under IAEA safeguards. The key issue here being the protection of classified information known as Restricted Data (nuclear weapons design information). If only unclassified materials are shipped to ANL-W, the entire ET process can be available for monitoring by the IAEA.

1.5.4 Process Description for Disposal of Plutonium Wastes in a HLW Repository

The repository facility for permanent disposal of plutonium waste forms consists of a surface facility (Figure 12) for receipt and handling of wastes, and a subsurface facility (Figure 13) for permanent isolation of the wastes from the accessible environment. The surface facility contains two separate areas: an operations area containing all the facilities for handling wastes that require radiological control; and a general support area consisting of "cold" facilities and the supporting infrastructure.

The disposal of immobilized waste forms in a repository is a solids handling process (Figure 14). The loaded transportation casks containing immobilized plutonium forms are inspected at the repository boundary, and moved to a radiologically controlled area. The plutonium waste from casks will then enter a waste handling building through air locks, where minor decontamination takes place. Wash waters from the decontamination operation are sent to a waste treatment facility. In the waste handling building, the sealed canisters containing immobilized plutonium waste forms are removed from the transportation casks and the canisters containing the immobilized plutonium transferred to disposal casks. These disposal casks are decontaminated, if necessary, and transferred to a shielded storage vault to await emplacement underground. The disposal casks are coupled to a transporter and moved to drifts for disposal.

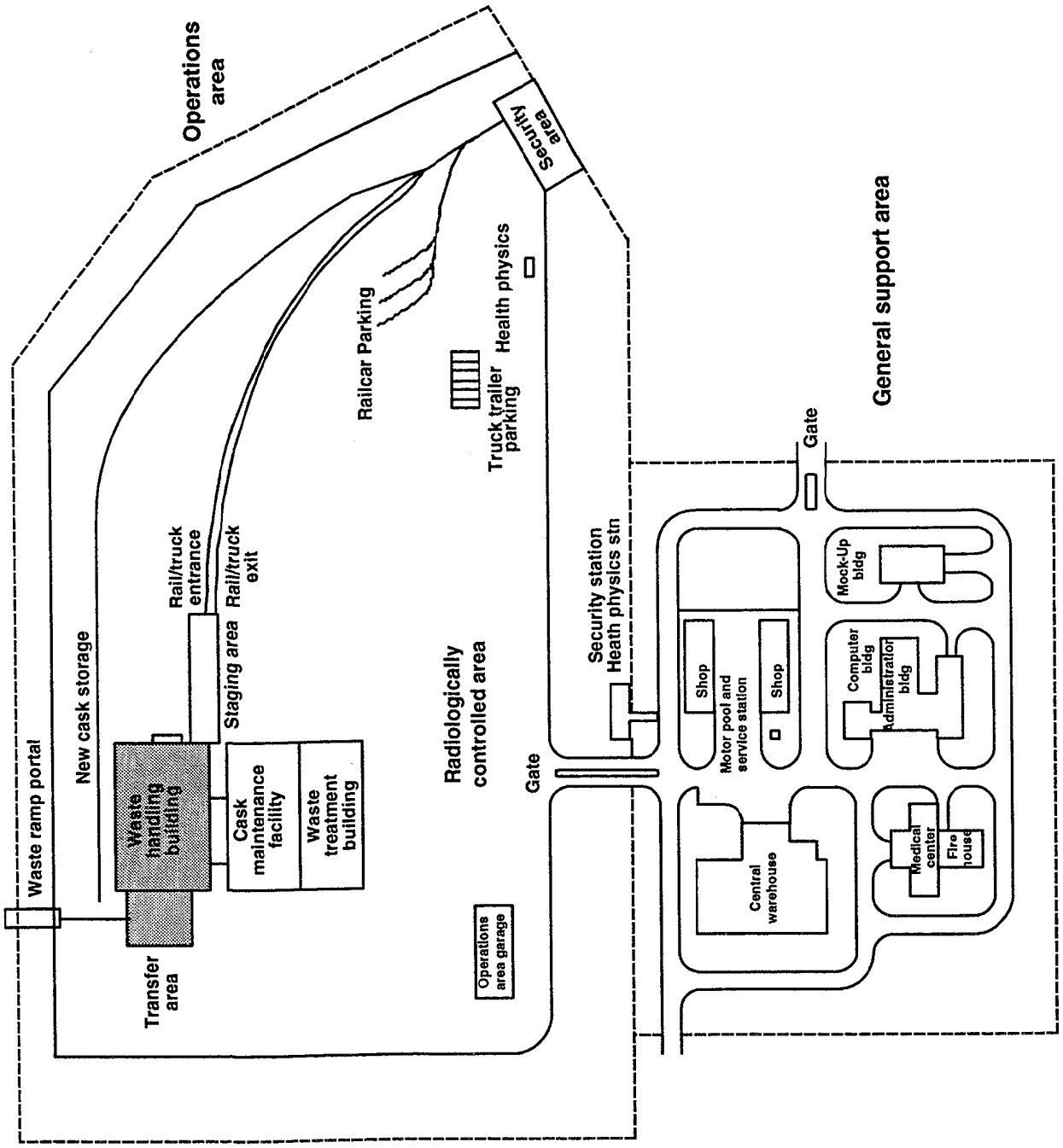

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Figure 12. Conceptual plan for repository surface facilities handling plutonium waste forms.

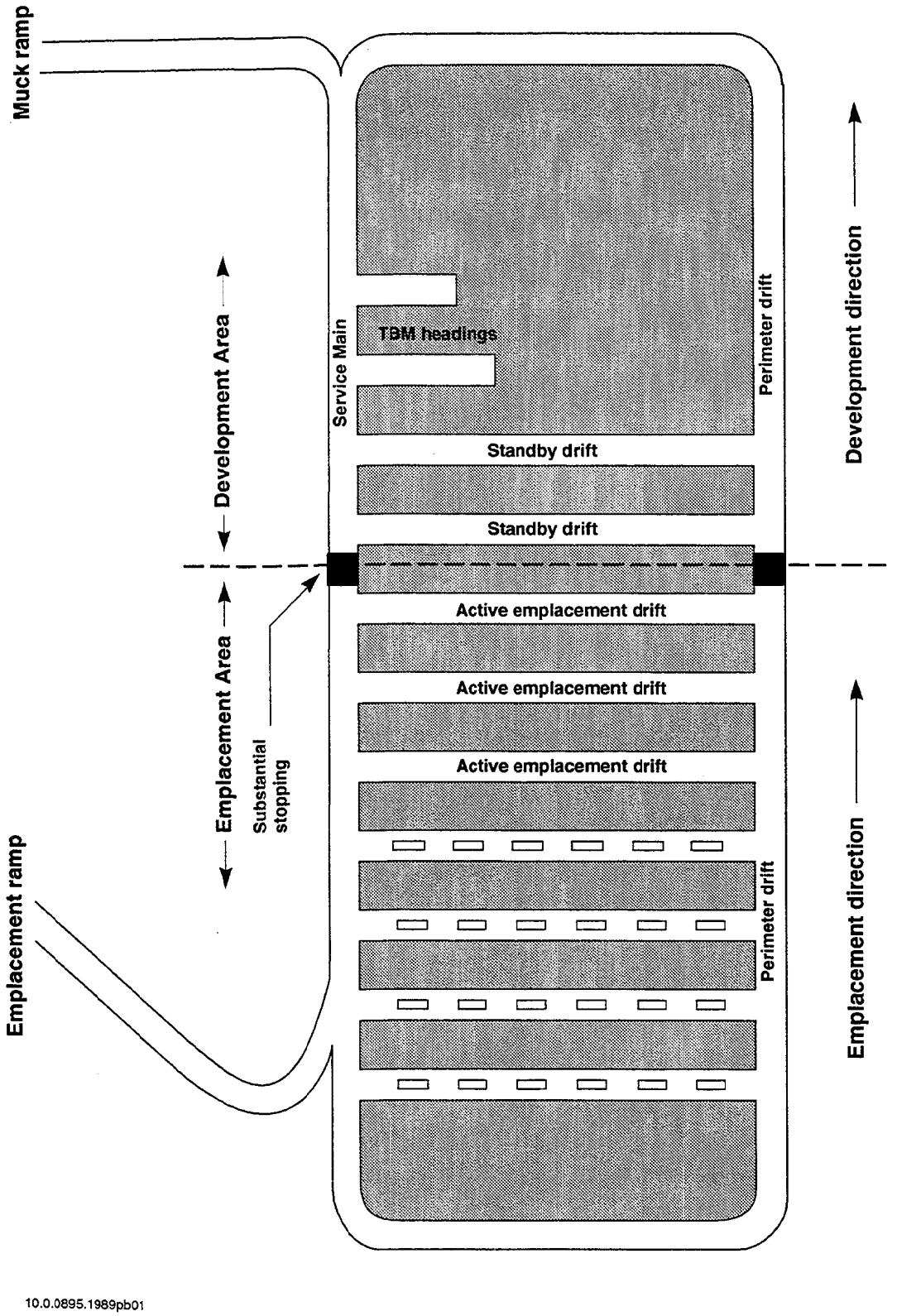

Figure 13. Conceptual layout for isolation of plutonium waste forms.

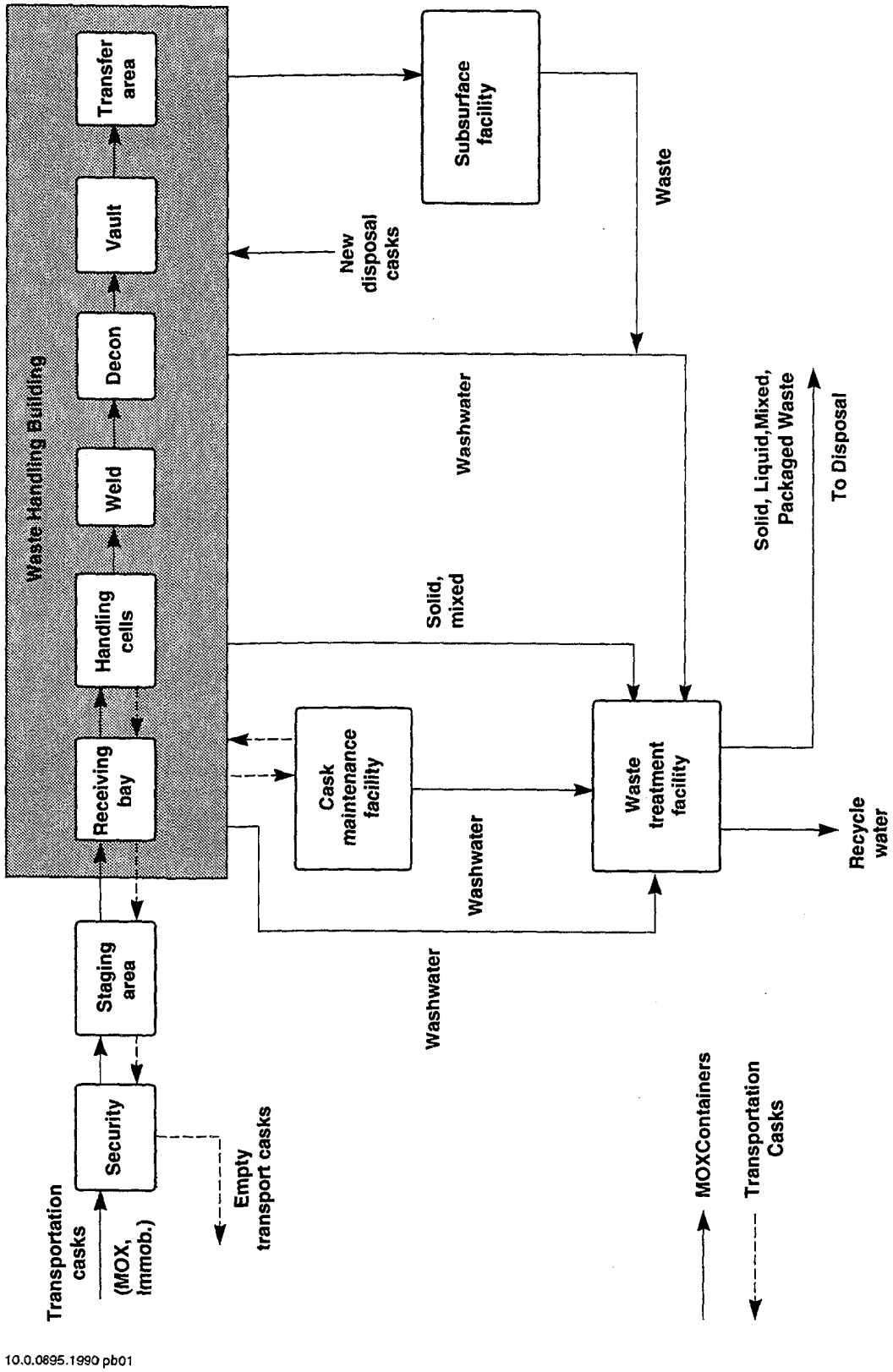

Figure 14. Conceptual process flow diagram for handling plutonium waste forms.

2.0 Criteria Assessment

2.1 Introduction

Section 2 examines technical issues associated with each step of the immobilization process from front-end processing to the final repository. This disposition variant is qualitatively assessed against the following eight criteria:

- Resistance to theft and diversion
- Resistance to retrieval by the host nation
- Technical viability
- Environment, safety, and health compliance
- Cost effectiveness
- Timeliness
- Fosters progress with Russia and others
- Public and institutional acceptance.

This end-to-end immobilization variant combines functions from facilities previously described in and bounded by the PEIS process currently underway. For front-end processing in this variant, elimination of aqueous recovery lines results in significant reductions in aqueous waste solutions, processing equipment, associated facility space, utilities, and support systems. The need for new facilities is reduced due to the availability of existing facilities at ANL-W.

2.2 Resistance to Theft and Diversion

2.2.1 Applicable Safeguards and Security Requirements and Measures

Domestic Theft and Diversion (Criteria 1). This criterion evaluates the system protection and resistance to theft by an outsider, or an insider and retrieval by outside groups after final disposition. Theft or diversion of material refers to both overt and covert actions to remove material from the facility. This is perpetrated by unauthorized parties including terrorists, subnational groups, criminals, and disgruntled employees.

Protection of the material and information from these parties is a domestic responsibility, not an international one. There are a number of possible adversary groups with different motivations and capabilities. The actions could be overt such as a direct attack on a facility, or they could involve covert measures which might utilize stealth and deception as well as possible help from an "insider." It is assumed that all

facilities will meet the necessary safeguards and security requirements. Therefore, many of the safeguards and security standards are not directly discussed in this document. The threats to facilities will be different depending on the form of the material, the activities at the facility, and the barriers to theft (both intrinsic to the material and also to the facility). For each of the facilities in this variant, a brief discussion is presented below of the potential risks to theft.

The safeguards and security requirements for this variant are primarily driven by the attractiveness of the material as defined in DOE Order 5633.3B and/or NRC requirements (10 CFR 73 and 74).

Material Form. An essential element in assuring the proliferation resistance of fissile material is the safeguards and security applied to the material, based on its form. The form of the material reflects the intrinsic properties of the material which dictates its attractiveness for use in nuclear weapons. However, the form of the material alone does not provide proliferation resistance. Safeguards and security systems should be applied in a graded approach based on the form of the material and its attractiveness.

DOE Category and Attractiveness Levels. The DOE defines the attractiveness level of nuclear material through a categorization of types and compositions that reflects the relative ease of processing and handling required to convert that material to a nuclear explosive device. Table 6 comes from the DOE Order for *Control and Accountability of Materials* (5633.3B) dated 9-7-94.

The level of protection accorded to an attractiveness level is dependent on the quantity or concentration of the material. Each category of protection has its own requirements ranging from the highest level of protection—Category I (assembled weapons) to Category IV (irradiated forms and less than 3 kg [6.6 lbs] of low-grade material). Protection of the material is accomplished through a graded system of deterrence, detection, delay, and response, as well as, material control and accountability. Layers of protection may then be applied to protect material of greatest attractiveness within the innermost layer and with the highest controls. Material of lesser attractiveness does not require as many layers of protection and fewer controls.

Category I and/or strategic fissile material must be used or processed within a DOE-approved Materials Access Area (MAA). The requirement for an MAA and vault-type room storage may mean that certain physical protection enhancements will be needed beyond what currently is present at existing facilities. The physical barriers at the protected area boundary normally consists of two barriers with a redundant intrusion detection system. The protected area boundary must also provide for a barrier from unauthorized vehicle penetration. The access control points into the protected area are normally made of a bullet resistant material. Duress alarms will be necessary at all manned access points. There will be enhanced entrance/exit inspections of personnel, vehicles and hand-carried items. MAA/protected area portals typically have metal detectors, fissile material detectors, and/or x-ray machines for hand-carried items.

2.2.2 Identification of Diversion, Theft, or Proliferation Risks

Tables 7–9 provide information about the material flow of plutonium through this variant, along with a description of the material and its changing attractiveness levels.

Plutonium Processing. The plutonium processing facility will be a Category I facility. A number of different forms are received by the plutonium processing facility (Cat. I-B through II-D). The oxide feeds will be converted into metal form with the lithium reduction step. Plutonium metal feeds and metal from lithium reduction will be

Table 6. (DOE) nuclear material attractiveness and safeguards categories for plutonium.

	Attractiveness	PU/U-233 category (quantities in kg)			
	Level	I	II	III	IV*
Weapons Assembled weapons and test devices	A	All quantities	N/A	N/A	N/A
Pure products Pits, major components, buttons, ingots, recastable metal, directly convertible materials	B	≥2 kg (≥4.4 lbs)	≥0.4 <2 kg (≥.9 <4.4 lbs)	≥0.2 <0.4 kg (≥.4 <.9 lbs)	<0.2 kg (<.4 lbs)
High-grade material Carbides, oxides, solutions (≥25 g/L) nitrates, etc., fuel, elements and assemblies, alloys and mixtures, UF_4 or UF_6 (≥ 50% U-235)	C	≥6 kg (≥13 lbs)	≥2 <6 kg (≥4.4 <13 lbs)	≥0.4 <2 kg (≥.9 <4.4 lbs)	<0.4 kg (<.9 lbs)
Low-grade material Solutions (1 -25 g/L), process residues requiring extensive reprocessing, moderately irradiated material, Pu-238 (except waste), UF_4 or UF_6 (≥20% <50% U-235)	D	N/A	≥16 kg (≥35 lbs)	≥3 <16 kg (>6.6 <35 lbs)	<3 kg (<6.6 lbs)
All other materials Highly irradiated forms, solutions (≥ 1 g/L), uranium containing <20% U-235 (any form or quantity)	E	N/A	N/A	N/A	Reportable quantities

* The lower limit for category IV is equal to reportable limits in this Order

Table 7. Safeguards and security environment.

	Environment							
Facility	Activity	Duration	Throughput	Waste streams	Lag storage	Max inventory	Intrasite transport	# proc steps
Plutonium Processing	Pit and mixed feed processing	40 hrs.	5 tonnes (5.6 tons)/yr	Yes	Yes	~2 tonnes (2.2 tons)	Yes	3
Intersite Transport	Pu feed to Immobilization Facility	N/A	5 tonnes (5.6 tons)/yr	No	No	N/A	N/A	N/A
Immobiliza-tion Facility	Immobilization in a glass-bonded zeolite waste form	TBD	5 tonnes (5.6 tons)/yr	Yes	Yes	50 tonnes (56 tons)	No	3
Intersite Transport	Immobilized matter to repository facility	TBD	5 tonnes (5.6 tons)/yr	No	No	N/A	N/A	N/A
High-Level Waste Repository	Receiving, NDA*, hot cells, lag storage	TBD	5 tonnes (5.6 tons)/yr	Yes	Yes	50 tonnes (56 tons)	Yes, to repository emplacement	N/A
	Emplacement in repository	TBD	5 tonnes (5.6 tons)/yr	No	No	50 tonnes (56 tons)	No	N/A

*As required

Table 8. Safeguards and security material form.

	Material Form						
Facility	Activity	SNM input	SNM Output	Conc. of Pu	SNM category-attractive-ness	Item mass/ dimensions	Self Protecting
Plutonium Processing	Pit and mixed feed processing	metal, oxide	metal and chloride oxide	> 90%	I-B - I-D	Various	No
Intrasite Transport	Pu feed to Immobilization Facility	N/A	N/A	> 90%	I-B - I-D	canister 14 x 51 cm (5.5 x 20 in.)	No
Immobiliza-tion Facility	Immobilization in a glass-bonded zeolite waste form	metal, oxide, and chlorides	glass-bonded zeolite waste form	In 90% Out 5%	In - I-B Out - IV-E	1680 kg (4,000 lbs) canister .6m x 3m (2'x10') stainless steel canister	In - No Out - Yes/Rad
Intersite Transport	Immobilized matter to repository	glass-bonded zeolite waste form	oxide in glass	5%	IV-E	87 tonnes (96 tons) ~2.5 m x 3.7 m (~8.5'X12')	Yes/Rad
High-Level Waste Repository	Receiving, NDA,* hot cells, lag storage	glass-bonded zeolite waste form	N/A	5%	IV-E	87 tonnes (96 tons) ~2.5 m x 3.7 m (~8.5'X12')	Yes/Rad
	Emplacement in repository	glass-bonded zeolite waste form	N/A	5%	IV-E	Emplacement packages	Yes/Rad

* As required

Table 9. Safeguards and Security Assurance.

	Assurance					
Facility	Activity	# of MBAs	Type of accounting	Nuclear measurement	Classified Matter	Accessibility**
Plutonium Processing	Pit and mixed feed processing	3	Bulk and item	Calorimetry, gamma, seg gamma neutron	in–yes out–no	THN
Intersite Transport	Transportation of Pu to Immobilization Facility	N/A	Item	N/A	No	THN
Immobilization Facility	Immobilization in glass-bonded zeolite waste form	3	Bulk and item	Weight, process data, gamma spec.	No	THN
Intersite Transport	Immobilized Material to HLW Repository	N/A	Item	N/A	No	CRY
High Level Waste Repository	Receiving, NDA*, hot cells, lag storage	4	Item	TBD	No	CRY
	Emplacement in repository	TBD	Item	TBD	No	CRY

* As required

** The materials can be touched, T, or are in a sealed container, C.
The container can be handled hands-on, H, or requires remote handling equipment, R.
The material/container target is in a large and/or bulky form that requires special handling equipment to be moved, Y, yes, or N, no.

converted to chlorides. For this facility most of the material is in a very attractive form with minimal intrinsic barriers. There are a large number of processing steps which provides increased opportunities of covert theft. Since many of the processes involve bulk material, the accountability measures will involve bulk measurements. In the case of an overt theft attempt, the targets of greatest concern would be the pits, pure metal, and oxides, which are very transportable. However, these materials would be under significant protection so that the risk associated with an overt event would be acceptable.

Immobilization Facility. In the initial stages of handling and processing the immobilization facility will be a Category I facility. Within the facility material will be changing form and concentration, decreasing the protection category and attractiveness. With the addition of a self-protecting property, the material meets the definition for Category IV-E.

At the immobilization facility, the plutonium and other TRU chlorides, $^{137}CsCl$, and other fission product chlorides will be loaded by ion exchange on a zeolite, reducing the attractiveness level. The ceramic bellows loaded with 5% weapons grade plutonium are transported in ANL HLW canisters. Eight of the canisters will be placed in each modified DHLW canister; five of the DHLW canisters will be placed in each rail shipping cask. The weight of the loaded cask is approximately 87 tonnes (96 tons). Once the immobilized material has been given a self-protecting barrier by the

introduction of radioactive "spike" material (cesium chloride or other high-level waste), the safeguards and security requirements are significantly reduced as the safeguards and security category is now that of IV-E (Highly radioactive material, i.e., a radiation dose rate in excess of 1 Sv [100 rems] per hour at a distance of 1 m [3 ft], is considered as Category IV-E). If after a period of time, the self-protecting barrier no longer meets the above radiation dose criteria, then it may be considered as Category III-D, depending upon the quantity of fissile materials present and the additional barriers that may exist at that time (as is true with commercial spent fuel). Protection against radiological sabotage should likewise not be significantly different than for existing commercial spent fuel.

The facility operations involve a large number of processing steps and relatively accessible bulk materials. As the plutonium is blended with matrix materials, the concentration of the plutonium decreases. Since these forms are still relatively accessible and transportable (prior to radiation spike), they are attractive targets for both covert and overt theft. After fabrication into canisters, they are much less transportable (more resistant to overt theft). Likewise, the fissile material within the canisters is no longer physically accessible and becomes subject to item accountancy, further reducing the opportunities for covert theft. There is some concern with the capability to perform accurate accountancy measurements after this processing occurs, especially after the addition of the radiation spike. However, it is reasonable to assume that containment and surveillance, coupled with accurate measurements prior to spiking, and item accounting thereafter, will be as acceptable in this facility as it is in others (i.e., spent reactor fuel). Research and development should be conducted to assure that the best technically viable methods can be used to satisfy the public and the international community that this concern for weapons program materials has been adequately addressed.

Repository. The immobilized material is received in shipping casks and the canisters are removed and placed into disposal casks. The material is highly radioactive and each cask weighs approximately 87 tonnes (96 tons). The material is a low attractiveness target for both covert and overt theft.

Risk Assessment

The measures identified for this criteria are the *environmental conditions, material form,* and *safeguards and security assurance.* These measures are briefly described below and a qualitative discussion of the relative risks is presented for each of the facilities in this variant. Tables 7–9 contain specific information derived from this report and other sources such as DOE Orders. Table 10 summarizes the potential risks. This assessment is highly qualitative and based on available data.

Environmental Conditions—This refers to the logistics, physical location, and the state during processing, transportation, or storage affect the opportunities for theft. The more complex the logistics (e.g., transfers and process locations), the more opportunities there are for theft. If the physical locations are more inaccessible (e.g., storage

locations), the opportunities for theft will be fewer. Table 7 summarizes safeguards and security environmental data.

Table 10. Potential risks for threats and Criteria 1 and 2.

	Plutonium conversion	Intersite transit	Immobilization Facility	Intersite transit	High level waste repository	After repository emplacement
Threat						
Covert Threat	High	Medium	High–Medium	Low	Low	Low
Overt Threat	Medium	Medium	Medium	Low	Low	Low
Diversion	High	Medium	High–Medium	Low	Low	Low
Criteria 1						
Material Form	High	High	High Medium	Low	Low	Low
Environment	Medium Low	Medium	Medium	Low	Low	Low
Safeguards and Security	High	Medium	High Medium	Low	Low	Low
Criteria 2						
Detection	High	Medium	High–Medium	Medium	Medium	Low
Irreversibility	High	High	High–Medium	Medium	Medium	Low

Plutonium Processing. This facility involves a large number of processing steps with a relatively high throughput. Based on the quantity and attractiveness of the material, this will be a Category I facility. Waste streams containing fissile material will be generated and they require monitoring to prevent possible theft or use as a diversion path. There will be lag storage in a active vault. There will be no intrasite transport movements (i.e., outside of the facility); safe secure trailer/transports will be used to deliver and pick up the material. Although operations for a single batch are relatively short, there will be a large number of batches needed to meet the proposed throughput obligations. Therefore, the opportunities for possible adversary actions are numerous.

Immobilization. The initial environment for the immobilization facility is very similar to that of the plutonium processing. This will be a Category I facility with a high throughput and a nearly continuous operation. Although safe secure trailer/transports will be used to deliver the material, they will not carry the lower attractiveness material leaving the facility. No intrasite transport will be required outside the MAA. Waste streams containing fissile material will be generated during processing activities.

Once the material has been immobilized, it will be stored in a separate location (Category IV-E) and the only transport will involve moving the canisters from the storage area to the repository. No fissile material waste streams are generated in storage.

Repository. The canisters are received in multipurpose canisters inside transport casks. In the surface staging area, the multipurpose canisters are removed from the

transport casks and placed into disposal casks. The disposal casks at some later time are moved to the subsurface facility and the casks are placed into the tunnel drifts. The casks enter the drifts through sealed doors that are opened to allow cask emplacement. The sealed doors secure the drift and waste packages; final "securing" will not occur until the end of the performance period (currently expected to be a 100 years from start of emplacement).

Material Form. Attractiveness is based on physical, chemical, or nuclear (isotopic and radiological) makeup of the nuclear material during processing, transportation, or storage. The risk of theft for weapons use is reduced if the material is only available in small quantities, the physical and chemical form of the material or matrix that makes recovery difficult, or the material has an unattractive isotopic content. Table 8 summarizes safeguards and security material form data.

Plutonium Processing. The material received at the plutonium processing facility is the most attractive material for this variant (e.g., pits, pure metal, and oxide). In the case of pit conversion, the attractiveness goes from I-B to I-C. For oxides and other high-grade material the attractiveness level remains at I-C. The material has overall very low intrinsic barriers, and is transportable. It has a very low radiological barrier primarily due to the presence of only small amounts of americium. In most cases, it is in a very pure form, as a metal or oxide, and its isotopic composition makes it usable for a nuclear device. Because pits and other weapons-usable materials are being processed, some of the material and waste streams will be classified.

Immobilization Facility. As in the case of the plutonium processing facility, the primary initial feed material is comprised of very attractive material (I-C). The intrinsic attributes of this material are the same as described above. Once the material has been blended, it would be more difficult to convert to a weapons-usable form. Additionally, the concentration of the plutonium is lower, substantially greater amounts of material would be required to produce a significant quantity. Once the material is placed into canisters, its chemical, isotopic, and radiological attributes would not change. Its mass/dimensions would increase, thus making it more difficult to move and easier to maintain surveillance, control, and accountancy.

With the addition of highly radioactive fissile products, chemical processing to convert the material into a weapons-usable form becomes much more difficult.

Repository. Since the immobilized canisters delivered to the repository are highly radioactive, intrinsic barriers are quite high. The radiological and isotopic attributes are time-dependent. Eventually the material would no longer be self-protecting because the radiological barrier would decrease by an order of magnitude in 90 to 100 years.

Safeguards and Security Assurance—The effectiveness of safeguards and security protection depends on the MC&A characteristics, and physical protection capabilities (not directly discussed here) of the processes and facilities. Table 9 summarizes safeguards and security assurances data.

Plutonium Processing. Material received into this facility (e.g., pits and containers with tamper indicating devices) would utilize item accountancy. Once the material has been removed from the "container" bulk accountancy would be necessary. Many of the items are small and many operations involve hands-on activities. In addition to destructive assay, other nondestructive assay (NDA) would be performed. As mentioned previously, the pits and some other material will be classified. This also applies to waste streams.

Immobilization. During the initial processing operations, bulk accountancy would be conducted. Once the material is placed into the immobilized canisters, item accountancy would be performed. Although devices are being developed to perform nondestructive assay on such items as fuel rods and other canisters, this is still a very time-consuming activity. Once the material is placed inside the canisters, it is no longer accessible, and it requires special handling equipment to be moved.

Item accountancy is used to account for canisters. Markings and seals on the canisters can also be used to verify material. Special handling equipment is required to move these canisters, and once they have a radiation barrier, remote handling is necessary. For immobilized-spiked material, some nondestructive assay measurements are possible, but they are generally used to confirm the presence of the radiation barrier and not to accurately account for the plutonium. Using the initial material information and the accountancy records from the facility processes, the quantity of material can be estimated.

Repository. Item accountability is used for the casks. No access is available to the material itself although access to the casks is possible. All movements of the casks require special handling equipment.

2.2.3 Ability to Achieve the Spent Fuel Standard

The "spent fuel standard" means that the material is as inherently unattractive and inaccessible as plutonium in commercial spent fuel. The final disposition form, environment, and safeguards and security for this variant meets the spent fuel standard. Both significant extrinsic (facility) and intrinsic (related to the material form) barriers exist. Since the radiological barrier is time dependent, this attribute will, over a long period of time, decrease and the material will not necessarily be self-protecting. Prior to the addition of the radiation spike, the material does not meet the spent fuel standard. Therefore protection commensurate with its attractiveness level must be provided.

2.2.4 Safeguards and Security Transportation Related Issues

For intersite Category I, material safe secure trailer/transports will be used to move the material between facilities. A secure loading/unloading area must be available to ship/receive, verify, and store the Category I material. The requirement for safe secure trailer/transport be removed only after the material has been given a self-protecting radiation barrier. With respect to other transport activities (e.g., between processing and storage), there are inherently fewer safeguards and security risks for overt theft

scenarios and a much lower risk for covert theft attempts. Minimizing the number and/or duration of the transport steps is desirable.

2.3 Resistance to Diversion, Retrieval, Extraction, and Reuse by Host Nation

2.3.1 Applicable Safeguards and Security Requirements and Measures

International Diversion, Retrieval, Extraction, and Reuse (Criteria 2). This criteria evaluates the systems resistance to diversion of material before final disposition by the weapon state itself, retrieval of material after final disposition by the weapon state itself, and conversion of the material back into weapons-usable form covertly by the host nation/state. Again the material form, environment, and safeguards are particularly important for detecting the diversion, retrieval and extraction activities. Additionally, the irreversibility of the material form is important for assessing its reuse in nuclear weapons. Nuclear material for this variant falls under the IAEA categories of unirradiated direct use. Some of the other fissile materials in the FMDP are not considered by the IAEA. The only existing world-wide inspection regime that exists to address this threat is the International Atomic Energy Agency (IAEA). One mission of the IAEA is timely detection of the diversion of nuclear material from declared nuclear activities. An important measure used by the IAEA is the "significant quantity," i.e., 8 kg (18 lbs) for plutonium. Since the state owns and operates the physical protection and material control and accountancy measures, the IAEA does not rely on these systems to fulfill their obligations. However, IAEA does independent verification of the data from the state's system of material control and accountancy. The IAEA, in performing its safeguards inspection activities, audits the facility records and makes independent measurements of selected samples of each kind of nuclear material in the facility. To help them fulfill their responsibilities, this verification is coupled with a technology known as containment and surveillance, which is designed to provide "continuity of knowledge" during inspector absence. Much of the containment and surveillance equipment used by the IAEA is very similar in technology, and in some cases nearly identical, to the seals and surveillance equipment used by national authorities in physical protection functions. Although the technologies may be the same, the objectives are different. For example, domestic requirements are usually monitored in real, or near-real, time. However, the IAEA may use unattended monitors (closed circuit TV recording, etc.) and return to a site only once every three months to check and verify activities.

The philosophies and implementation of international safeguards (commonly referred to as IAEA safeguards) are substantially different from domestic safeguards and security that DOE and NRC practice. It is likely that these activities will require additional accountability verification (e.g., identification, weighing, sampling and nondestructive analysis), increased inventories and item checks, containment and surveillance measures installed throughout the facilities (e.g., surveillance, seals, monitors, tags), space for inspectors and equipment for independent measurements by international inspectors. Additionally, classified and other sensitive information may need to be protected differently from what might currently be implemented, because of

the presence of IAEA uncleared foreign national inspectors. Under current laws, certain information cannot be divulged to IAEA inspectors (e.g., disclosure of weapons design information violates the Atomic Energy Act and the 1978 Nuclear Nonproliferation Act). Therefore at least part of these facilities may not be under international safeguards. Verification by the IAEA is not possible, until agreements between the IAEA and the U.S. can be accomplished. A number of different options are being considered which address this problem.

Possible Diversion, Reuse and Retrieval Risks. The threat for this criteria is the host nation. Although the host nation may choose to use overt measures to obtain material, the greatest concern is with covert diversion and retrieval. Because the state has responsibility for physical protection and material control and accountability, the IAEA will independently verify material accounting. Containment and surveillance is used to complement the material accountability measures. The vulnerability to diversion is dependent on the material form and the ability to retrieve and convert the material into a weapons-usable form. Therefore, if we were to evaluate each of the facilities for this variant, there may be some differences. Because of inherent limitations on the accuracy of nondestructive analysis measurements, there is an increased risk of diversion at high-throughput facilities. This is where containment and surveillance plays an important role in assuring material accountability. For each of the facilities in this variant, a brief discussion is presented below of some of the potential risks to diversion. Existing domestic protective measures will help mitigate these risks. A covert attempt to divert a significant quantity will require multiple accomplices and greater amounts of MC&A steps to be subverted to avoid detection.

Plutonium Processing. Because this facility does significant processing and is handling large quantities of material, there is an increased risk for possible diversion. The high attractiveness or direct weapons-use capability of the material in this facility conversion and reuse are easier. The ability to detect these covert activities in a timely fashion is diminished.

Immobilization Facility. Similar issues in this facility exist for the initial process operations as for the plutonium processing facility. After the material has been blended, it becomes a less attractive target. Once the material is placed into canisters, and item accountancy is used, the possibility for diversion is reduced. Because the canisters are large and require special handling equipment, containment and surveillance measures can more easily detect diversion attempts.

After the radiation barrier has been added, the material attractiveness for reuse is significantly reduced.

Repository. The high intrinsic barriers of the canisters and large mass of the casks make diversion more difficult. Since the radiological barrier is time dependent, it is necessary that other measures be utilized to help minimize the threat of diversion. Placement of the material in an underground repository makes retrieval of this material extremely difficult. Additional safeguards and security and containment and surveillance measures should be utilized to help safeguard this material, particularly

for long time periods. It is also important that high accountability of the material be maintained, so that there is the highest level of confidence that the material was not diverted and was in fact placed into the repository.

Again the measures of the environment, material form and safeguards and security contribute to this criteria. Thus the information found in the provided tables are applicable, however the capabilities of the adversary (e.g., the host nation) must be considered when analyzing this information. Table 7 summarizes the analysis for Criteria 2. As for Criteria 1, the following discussion is very qualitative and must be refined as more information can be made available that can be used to conduct more comprehensive analysis. The primary measures are the irreversibility of the material forms (e.g., the ability to convert the material into weapons-usable form) and the ability to detect diversion, retrieval and conversion. The performance measures which would demonstrate effectiveness in this area are in the following terms:

Difficulty of Diversion, Retrieval, Extraction, and Reuse. This establishes the timeliness and irreversibility criteria and the level of safeguards required.

Plutonium Processing. This facility involves very attractive material and high throughputs. The accessibility of the material, low intrinsic barriers, and the large number of processing steps makes the risk to possible diversion a concern. Once the material has been diverted, the pure metal and oxide could be reused in a nuclear device relatively easily. Because pits and other material in this facility are classified, they would not be under international safeguards unless restricted data could be protected.

Immobilization Facility. The attractiveness of the material in the early processing steps is similar to the plutonium processing activities. When the material is blended the concentration of plutonium is decreased and a much greater quantity of material would need to be diverted. Once the material is blended and placed into canisters the material becomes more difficult to divert. If diversion does occur chemical barriers exist to make conversion and reuse expensive and time consuming.

Once the material has been given the radiological barrier, handling the material becomes more difficult and thus the risk of diversion and reuse are lower (spent fuel standard).

Repository. The high radiological barrier coupled with storage of the material in massive casks in a deep geologic repository makes diversion very difficult, expensive, and easily detected by containment and surveillance measures. Even if the material could be diverted, a considerable effort would be required to convert this material into a weapons-usable form.

Assurance of Detection of Retrieval and Extraction. The difficulty of detection or diversion of a significant quantity of material depends on the following factors:

- Ability to measure material which includes processing that is underway, accuracy of applicable nondestructive analysis techniques, the presence of waste

streams, and classification issues which may prohibit measurement, and whether item accountancy instead of bulk accountancy methods can be applied.

- Containment and surveillance systems.
- Timeliness of detection.

Plutonium Processing. This facility will involve large quantities of bulk material and very high throughputs. This makes material accountability very difficult and in some ways inadequate for the IAEA requirements. It will be necessary to have containment and surveillance, as well as, other safeguards and security measures, to ensure that material is not being diverted. The presence of classified material/information further complicates safeguards with respect to international inspection.

Immobilization Facility. The problems discussed with the plutonium processing facility (except there is no classified material) exist in the initial operations in this facility. After the material has been blended, a greater amount of material will be required to accumulate a significant quantity. Once it has been placed into canisters, the individual items will be accounted for, and this will increase the ability to detect diversion.

After the material has a radiation barrier, it will require special and remote handling equipment. The barrier will reduce the risk of diversion, and increase the probability of detection.

Repository. The waste packages will be sealed, item accountancy performed, and containment and surveillance measures implemented. Because the size and mass of these casks is quite large, the risk to diversion is lowered. The emplacement of this material in a HLW repository, along with continuing containment and surveillance measures, will ensure the risk after disposition remains acceptable.

2.4 Technical Viability

2.4.1 Technical Viability of Front End

The front-end disassembly and conversion consists of several different processes to convert plutonium storage forms to those needed by the immobilization back end.

Most of the processes used in the front end are on the industrialization scale. The major process not in current use is hydriding/chlorination which is at the demonstration stage. The remaining technologies are in the engineering-scale testing or transitioning into the industrialization stage.

DC-01 Truck and CRT Handling and DC-02 Offsite Receiving/Shipping. The operations in this area involve material handling techniques which have been utilized throughout the DOE complex for many years. Initial accountability confirmation analyses utilize nondestructive analysis technology that has been routinely used for production operation. Storage of shipping containers in a facility with an automated

stacker-retriever system has been demonstrated at several sites. Accurate accountability measurements will utilize standard nondestructive methods such as calorimetry and segmental gamma scanning.

DC-03 Gas Sampling. The internal gas pits will be sampled utilizing a laser system similar to one utilized in production operations at the Pantex site. Improvements in the system are currently under development at the Los Alamos National Laboratory.

DC-04 Special Recovery. The processes for handling contaminated pits have been demonstrated on a production scale at the Los Alamos National Laboratory.

DC-05 Pit Bisectioning. Disassembly of pits has been performed on a production-scale at the Rocky Flats plant using modified lathe technology. Improved techniques and equipment which cut the pits without the formation of chips and turnings are under development at the Lawrence Livermore National Laboratory.

DC-07 Calcination and Passivation Furnace. The calcination and passivation furnace is basically a muffle-type furnace which is commercially available. Plutonium-bearing materials (e.g., glove box floor sweepings) have been oxidized in this type furnace for many years throughout the DOE complex.

DC-08 HEU Decontamination. HEU parts have been decontaminated by nitric acid washing at Rocky Flats on a production-scale for several years. Los Alamos National Laboratory is developing an electrolytic process which is expected to significantly reduce the generation of liquid waste. Feasibility of the process has been demonstrated on a laboratory-scale, but requires demonstration on a production scale.

DC-09 Fuel Decladding. These operations are currently used in industrial-scale processes.

DC-10 Size Reduction. Size reduction of plutonium oxide utilizes vibratory grinding which is a standard operation in commercial industry. Plutonium grinding has been performed on production-scale in the manufacture of mixed oxide fuel (plutonium/uranium oxide fuel).

DC-11 in Process Storage. This interim lag storage of oxide will be similar to the vault-storage techniques used in DOE complex facilities for many years.

2.4.2 Technical Viability of Back End

The technical viability of the electrometallurgical treatment variant can best be assessed by examining the degree of development of each of the process steps. The process steps are discussed in the following:

Cesium Capsule Receiving. The receiving, handling, and storage of the cesium capsules require facilities and expertise in handling highly radioactive sources. This is a mature technology, requiring no further development.

Cesium Capsule Shearing. Decay of monovalent cesium to form divalent barium will result in a chloride-deficient product containing metallic barium. Therefore, the capsules are not opened in air, because of the risk of pyrophoricity of finely divided barium metal. The ET variant will be operated in a high-purity argon atmosphere, thus no risk of fire will be present. The problem is thus reduced to one of handling dispersible, very highly radioactive source material. Although considerable experience exists for similar operations, cesium capsule shearing will require careful design and planning. No development effort is required.

Metal Feed Preparation. The metal cutting and anode basket loading operations are simple and require no development.

Oxide Feed Preparation. Preparation of plutonium-rich oxides for the lithium reduction is simply a matter of loading the oxides into suitable reduction containers, and this requires no development. While the magnesium-chloride extraction step has been done in small-scale experiments, its routine operation is less developed. Some development will be required for this step.

Lithium Reduction. The lithium reduction step has been demonstrated at the 10-kg engineering scale using simulated spent light water reactor fuel (unirradiated). A laboratory demonstration of this step with spent Commonwealth Edison light water reactor fuel (0.5 kg) has also been done successfully.

The separation of solid uranium particles from the molten salt of LiCl-Li_2O has been done on a 20-kg scale by sieving with metal screens. The ANL is developing a submersible centrifuge that may facilitate this separation.

Many smaller-scale lithium reductions have been conducted, and the results are routinely predictable. No experiments have yet been done with pure PuO_2. Further development and then scale-up is required.

Lithium Regeneration. Lithium regeneration from molten LiCl has been done routinely at Oak Ridge, and many small-scale experiments have successfully demonstrated the technology at Argonne. Lithium regeneration has been demonstrated at the 10-kg scale in conjunction with the simulated spent fuel reduction demonstration. Some additional demonstration is necessary to assure that the technology can be used on a production basis. This is a moderately mature technology.

Electrorefining. The electrorefining of simulated spent fuel on a 10-kg (22 lbs) scale has been operated routinely for over seven years at Argonne National Laboratory. A full-scale system capable of treating spent fuel as begun operation at ANL-W. This is a mature technology.

Salt Blend Tank. Melting, mixing, and handling molten halide salts is a mature technology, requiring no further development.

Zeolite Sorption. Zeolite sorption of molten chloride salts has been under development for over five years as part of Argonne's spent fuel treatment activities. The chemistry of ion exchange and salt occlusion in zeolite is well understood, but the technology has not been demonstrated on a large scale. The current scale of the development technology is approximately one kg total mass. This technology requires additional development with plutonium and scale-up.

Hot Press GBZ Form. Fabrication of the GBZ waste form is being studied at the 10–100-g (.35–3.5 oz) scale. Screening tests are underway to select the best glass frit to produce an immobilization form having optimum properties of leach resistance and mechanical properties. This requires some additional development and scale-up to the engineering and then process scale.

Canister Loading, and Weld and Test. These last two process steps are mature technologies, requiring no further development. Containers must be qualified for disposal.

In summary, all of the process steps for the electrometallurgical treatment variant are mature technologies with the following exceptions: 1) zeolite sorption of molten salts requires additional development, 2) hot-pressing to make the glass-bonded zeolite immobilization form requires additional development, and 3) magnesium extraction to solubilize plutonium oxide residues requires additional development. The results of this assessment indicate that the electrometallurgical treatment variant is viable.

2.4.3 Technical Viability–Repository (ET)

Regulatory Risk. Any waste form accepted for disposal in a HLW repository must comply with the provisions of the Nuclear Waste Policy Act, as amended (NWPA). According to Section 2(12)A of the NWPA, the definition of high-level waste does not explicitly include a glass-bonded zeolite form loaded with plutonium. However, under Section 2(12)B of the NWPA, the NRC has the authority to classify this waste form as high-level waste through rulemaking. Such rulemaking or clarification in the authorizing legislation will be necessary before this waste form can be considered for disposal in an NWPA repository. The final disposal of this waste form will have to follow the licensing provisions of 10 CFR Part 60 and the applicable NEPA process. Further, it is current policy of the DOE not to accept any wastes that include components regulated as hazardous under RCRA in the first HLW repository; absence of such RCRA regulated materials will have to be demonstrated prior to acceptance into the repository.

Technical Risk. The primary technical viability and risk issue related to the disposal of immobilized glass-bonded zeolite waste forms in a repository is associated with long-term performance. This is necessary to satisfy the licensing requirements of 10 CFR 60. The long-term performance issues are comprised of doses to a population in the accessible environment, and maintaining criticality (as fabricated, degraded mode, and external) control during all phases of the repository operation, including the period of isolation.

The contributions to dose by the glass-bonded zeolite waste form appears to be small compared to that predicted from uranium-based commercial spent fuel. However, the cumulative doses, from both the commercial spent fuel and the glass-bonded zeolite must be shown to be within the envelope permitted by regulation. Since the EPA has remanded the regulation governing long-term performance and since a repository has not yet been licensed, calculations of such cumulative effects are not currently possible.

The NRC regulations for criticality control require that "the calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation. [10 CFR Part 60.131 (b) (7)]. Preliminary calculations on as-fabricated criticality for the glass-bonded zeolite option, with a 1:1 molar ratio of plutonium to neutron absorber, shows that the k_{eff} of 0.95 or less as prescribed by NRC can be met. The effects of waste form and waste package degradation and the potential loss of neutron absorbers on criticality control are currently uncertain. An experimental program and further analyses are underway to assess these risks.

Although the NRC allows only limited credit for neutron absorbers for the commercial SNF, in recent communications with DOE, the NRC has postulated the potential use of low-solubility neutron absorbers for weapons plutonium for criticality control. This suggestion has been made as part of the early development efforts that DOE should undertake in establishing a strong rationale for criticality control, especially where excess weapons-usable fissile materials are being disposed in a repository. The experimental program and additional analyses are completely consistent with these suggestions.

2.5 ES&H Summary (Deltas/Improvement over PEIS)

The PEIS analysis currently underway is based on individual data calls for separate pit disassembly and conversion, conversion and stabilization, and immobilization facilities.

This end-to-end immobilization variant combines functions from the previously described facilities. The PEIS impact analysis is considered bounding for this variant, however, facility consolidation and process simplifications and improvements result in substantial ES&H improvements over the bounding case being analyzed in the PEIS. These improvements are discussed below.

2.5.1 Front End

The front-end processes for immobilization presented in this report offer substantial ES&H improvements over the base case being analyzed in the PEIS.

The pit disassembly and conversion and plutonium conversion and stabilization new facilities and process flow diagrams being analyzed in the PEIS are the base case. They produce clean metal or > 50% oxide to meet the long-term storage standard. This requires residue processing lines that generate aqueous waste solutions.

For this variant, all the front-end processes will take place in facilities at ANL-W. The total floor area required for the front-end plutonium processing functions is approximately 15,000 sq ft for plutonium processing, 20,000 sq ft for direct plutonium processing support, and 50,000 sq ft for auxiliary support functions. The rest of the available space in ANL-W and requirements for new space is being evaluated.

The front-end flow diagram for immobilization has been tailored and simplified to meet the immobilization process requirements. Aqueous recovery lines and process steps to purify oxide have been eliminated since impure oxide is satisfactory feed for the immobilization process. The process to separate plutonium from uranium solutions has been eliminated.

These changes result in significant reductions in aqueous waste solutions, processing equipment, associated facility space, utilities, and support systems. Personnel radiological exposure will also be reduced since the eliminated equipment will not be operated, maintained, decontaminated and decommissioned.

2.6 Costing Data

The approach to costing the ET variant and its variants is a life-cycle cost (LCC) methodology. These costs are then analyzed and laid out against the end-to-end variant schedule to provide constant dollar cash flows which can then be discounted at the appropriate real discount rate. The two major figures-of-merit for each variant are the constant dollar up-front costs, i.e., all life-cycle costs prior to normal operation of each facility (this is what the government must spend to develop, design, construct, and startup a given facility), and the discounted total life-cycle cost, which includes all "cradle to grave" project costs paid by the government and including front-end costs, revenues (if any), recurring costs, and end-of-life costs.

"Lump sum" constant dollar costs for each major facility were developed. Schedule considerations only affect the way in which the lump sum costs are "spread." (Each lump sum cost, however, must have a baseline schedule which is compatible.) The following Table 11 summarizes the lump sum constant dollar costs by facility. (Costs are in millions of 1996 dollars). Two cases are presented. The base case assumes the use of the ANL-W facilities for the immobilization mission alone. The second case represents the concurrent sharing of the facilities between the immobilization and spent fuel programs. The lower costs in this second case results from sharing of facility operating costs between these two programs. Operating assumptions and design bases for front-end and back-end costing are presented in Table 12.

Table 11. Summary constant dollar life cycle costs for ET ($M 1996).

Facility	Pu processing	Immobilization	Repository	Total end-to-end variant
Base case — immobilization program only				
Up-front costs	730	460		1190
Other life cycle (10 yrs of operations) plus D&D	890	870	480	2240
Total life-cycle costs	1620	1330	480	3430
Shared case — with spent fuel program				
Up-front costs	730	460		1190
Other life-cycle (10 yrs of operations) plus D&D	890	320	400	1610
Total life-cycle costs	1620	780	400	2800

Note: Reflects final System Analysis values, ORNL, 11/9/95, with agreed to adjustments.

Table 12. Front-end and back-end operating assumptions and design basis.

Assumptions	
Plant capacity	5 tonnes (5.6 tons) Pu/yr
Average plant throughput	25 kg (55 lbs) Pu/day
Plant location	ANL-W
Plant owner	U.S. Government (DOE)
Process building type	Seismic Category 1 for Pu handling areas
NEPA, safety, permitting	DOE
Feedstocks: Front end: Back end:	 Pits and other surplus Pu forms Plutonium oxide, chloride, and metal
Plant operational lifetime/total Pu processed	10 years to dispose 50 tonnes (56 tons) Pu
Time from ROD to hot startup (front end)	10 years
Data source for cost information	LANL and LLNL
Time from ROD to hot startup (back end)	13 years

The estimated duration of the plutonium immobilization campaign will be 10 years. Operations shall be three shifts per day, seven days per week. Allowing normal time for remote maintenance, accountability, criticality control, etc., a normal operating year should be 200 days.

2.6.1 Plutonium Processing (Non-Remote Handled) Operating Assumptions

Table 12 shows the major operating assumptions for the plutonium facility, which contains all of the non-remote handled operations. Since such an operation is dominated by the shipping/receiving and recovery operations, our assumptions are that all non-remote handled operations for the end-to-end variant will be contained in a single plutonium facility. Specific examples include all plutonium recovery operations and all immobilization operations not involving the use of radionuclide spikes such as ^{137}Cs or high-level waste. Such operations require similar glove box and ventilation systems as those used for the recovery operations and would not be contained in a separate facility in any reasonable implementation.

The facility sizing and cost estimates were developed using the cost estimating procedure outlined above and are based on the second-level flow diagrams for this facility. R&D costs are those for the specific operations identified on the second-level flow diagrams which can be performed in a standard plutonium processing facility (e.g., non-remote handled operations, only glove box operations). Post construction startup costs are estimated as 1.5 years of operating costs based on the anticipated startup schedule. Waste disposal costs are based on plutonium throughput and are costed at $10,000 per drum for TRU waste and $2,000 per drum for low-level waste.

Table 13 shows the summary of the plutonium processing LCC costs for the base case.

2.6.2 Back-End Immobilization Costs.

The back-end remote-handled facility costs are estimated at a preconceptual level for the ANL-W site.

The pricing level is based on 1996 dollars. Escalation is excluded. The estimates also assume a normal schedule without delays. Cost exclusions are cost of land, roads, and utilities outside fence line, research and development costs, NEPA, licensing and permitting costs, and site qualification, postconstruction startup, waste handling and disposal, oversight, revenues and intersite transportation.

The estimates are based on new major process equipment, process support systems, utility and service systems, plant buildings and site requirements. The method of estimating is based on the following:

- New major process systems—equipment cost and cost per item plus cost of bulk materials (piping, etc.)

Table 13. Plutonium processing LCC Summary for ET ($M 1996).

End-to-end variant	Cost	Basis
"Preoperational" "up-front" costs		Per SA model
1. R&D	45	R&D estimate LANL/LLNL
2. NEPA, licensing, permitting	35	
3. Conceptual design	9	
4. Q/A, site qualification, S&S	7	
5. Postconstruction startup	54	
6. Risk contingency	38	
Sub OPC	188	
"Capital" or "TPC" up-front costs (TEC)		
7. Title I, II, III engineering, design & inspection	81	
8a. Capital Equipment	130	
8b. Direct & indirect construction/modification	201	
9. Construction management (% of category 8)	20	
10. Initial spares (technology dependent)	2	
11. Allowance for indeterminates (AFI) (% of Cats 7–10)	108	
12. Risk contingency	0	
Sub TEC	542	
Total up-front cost	730	
13. Operations & maintenance staffing	358	
14. Consumables including utilities	94	
15. Major capital replacements or upgrades (% of capital)	240	
16. Waste handling & disposal (TRU, mixed and LLW)	83	Unit costs from ORNL
17. Oversight—DOE or NRC	10	
18. M&O Contractor fees	16	
19. Payments-in-lieu-of-taxes to local communities (PILT) (1%)	8	
20. D&D	56	
21. Revenues (if applicable)	0	
22. Government subsidies or fees to private-owned facilities	0	
23. Transportation of Pu forms to facility	25	ORNL T & P estimate
24. Storage of Pu at existing 94-I site facility		
Sub other LCCs	890	
Total LCC (front-end fac.)	1620	

- New process support systems—capacity and size x factor
- New utility and service systems—capacity and size x factor
- Plant buildings (facilities)—cell and building size, type of construction, HVAC, special features (lined cells, etc.)—$\$/ft^2$ or $\$/ft^3$.

Noteworthy preoperational costs include R&D, waste form qualification NEPA/licensing, and costs for core team from completion of Title II design to award of license.

The capital cost estimate includes direct costs, indirect field costs, total field costs, contractors costs and profit, construction management, A-E cost, management costs, initial spares, decontamination and decommissioning costs and contingency.

The operation and maintenance (O&M) cost estimate includes costs for personnel wages, consumables, material and maintenance expenditures, and waste disposal.

The cost for facility maintenance and spares is estimated using a factor of 4% of facility capital costs. Consumables items such as chemicals are base on data in *Chemical Marketing Report*, dated 1989. The cost for utilities and services, including materials, safety, environmental and security to operate the facilities, is estimated using a factor of 10% of the personnel wages. These cost factors are based on previous experience with projects of similar scope.

Waste disposal is based on unit volume costs for disposal of transuranic (TRU) waste to the Waste Isolation Pilot Plant (WIPP) and low-level solid wastes to a shallow land burial site. A 15% contingency is included in the operating cost.

Table 14 shows the summary of the back-end immobilization processing LCC costs for the base case.

2.6.3 Repository Costs

The estimated cost for disposal of the immobilized waste forms in a repository is based upon information contained in the Federal Register notice (52.FR 31508) published by the Department of Energy on August 20, 1987 entitled *Civilian Radioactive Waste Management: Calculating Nuclear Fund Disposal Fees for DOE Defense Program Waste.* This document from the Office of Civilian Radioactive Waste Management (OCRWM) is a public notice of its approach to interpreting the requirement under the Nuclear Waste Policy Act of 1982 for allocating the costs of developing, constructing, and operating repositories between atomic energy defense wastes and commercial high-level spent fuel.

In this notice, DOE identified a preferred cost sharing approach between defense and civilian wastes. According to the formula, the repository cost per canister of DHLW is approximately $500K based on a total life cycle cost analysis completed in September 1995, "Analysis of the Total Life Cycle Cost of the Civilian Radioactive Waste

Table 14. Back-end immobilization LCC summary—ET ($M 1996).

End-to-end variant	Cost 1995 $M	Basis
"Preoperational" or "OPC" costs		
1. R&D Waste form qualification	39 80	R&D estimates
2. NEPA, licensing, permitting Conc A/E and program team from end of Title II to issue of license	22 28	$10 M/yr x 3.5 yrs
3. Conceptual design	3	
4. Q/A site qualification, S&S	9	
5. Post-construction startup	69	
6. Risk contingency	63	
Sub OPC	313	
"Capital" or "TPC" up-front costs (TEC)		
7. Title I, II, III engineering, design & inspection	27	Include Program Management
8a. Capital Equipment	(in 8b)	
8b. Direct & indirect construction/modifications	58	
9. Construction management (% age of category 8)	7	
10. Initial Spares (technology dependent)	15	
11. Allowance for indeterminates (AFI)	38	
12. Contingency	0	
Sub TEC	146	
Total up-front cost	459	
Other life cycle costs		
13. Operations & maintenance Staff size (410)	461	
14. Consumables including utilities (10 years)	64	Chem Marketing Price Report
15. Major capital replacements or upgrades (% of capital)	116 96	4% of Facility Capital Cost 15% total operation cost continging
16. Waste handling & disposal	10	
17. Oversight—DOE or NRC	10	
18. M&O Contractor fees	15	
19. Payments-in-lieu-of-taxes to local communities (PILT) (1%)	7	
20. D&D	14.6	
21. Revenues (if applicable)	0	
22. Government subsidies or fees to private-owned facilities	0	
23. Transportation of Cs^{137} to facility	75	
24. Storage of Pu at existing 94-I site facility	0	
Sub other LCC	869	
Total back-end LCC	1328	

Management Program," DOE/RW-0479, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, September 1995."

2.7 Schedule

2.7.1 Overall

A preliminary, estimated schedule to deploy, operate, and decommission (or convert) the electrometallurgical treatment immobilization variant facilities has been developed by combining schedules for the front-end and immobilization facilities. This combined schedule is presented in tabular form in Table 15 and Table 16 and in Gantt chart form in Figure 15 and Figure 16. The currently scheduled date of the Programmatic Environmental Impact Study (PEIS) record of decision (ROD) is in the last quarter of 1996.

A new capital project will be required to implement the electrometallurgical treatment plutonium immobilization variant, which includes the design and construction of modifications to existing DOE ANL-W facilities for front-end and immobilization facilities. An assumption is that DOE line item projects will be conducted in accordance with DOE Orders and the congressional funding cycle. The planning basis is that Key Decisions (KD) for Approval of Mission Need (KD-0), Approval of New Start (KD-1), Commence Detailed Design (KD-2), Commence Construction (KD-3), and Commence Operations (KD-4) will be performed by the DOE in support of this plutonium immobilization variant.

An R&D program has been identified to develop and demonstrate the process and equipment.

National Environmental Protection Act (NEPA) activities are included. For the electrometallurgical treatment with modifications to existing DOE ANL-W facilities for front-end and immobilization facilities, it is assumed that a site-specific Environmental Impact Statement (EIS) will be required following the programmatic EIS. After the final EIS and its ROD, Title II design for the front-end and immobilization facilities could begin, were it not constrained by waste form certification and qualification.

Permitting activities are indicated. Preparation of a Safety Analysis Report is included. Title I and Title II (preliminary and detailed) design durations are indicated. Construction and procurement durations are included. Cold startup, preoperational testing, and an Operational Readiness Review (ORR) of the facility is included, followed by hot startup and operations.

The time to process the reference 50 tonnes (50,000 kg) of plutonium will vary with plutonium loading and actual operating scenarios. For planning purposes, the estimated duration of the plutonium immobilization campaign is 10 years. (Detailed performance modeling by systems analysis presented in other sections of this report may indicate variations from the nominal 10 years planning basis). Process

improvements, plutonium immobilization experience, and increased plutonium loading could shorten this schedule.

Table 15. Front-end facility schedule breakout.

Task no.	Task name	Duration	Start date	Finish date	Predecessors
1	Congressional funding and initial activities	87d	10/2/95	9/5/00	
2	ROD KD 0 Approval for Mission Need	0d	1/1/97	1/1/97	
3	Title I Authorization Process	104w	1/1/97	12/29/98	2
4	Full Funding Authorization Process	88w	12/30/98	9/5/00	3
5	R&D funding	0d	10/2/95	10/2/95	
6	A-E selection	12w	1/1/97	3/25/97	2
7	Select NEPA contractor	12w	1/1/97	3/25/97	2
8	R&D, demo, test, integrated prototyping and proc. eng	1584d	10/2/95	10/25/01	
9	HYDOX	522d	10/2/95	9/30/97	5
10	NDA	522d	10/2/95	9/30/97	5
11	Bisector	522d	10/2/95	9/30/97	5
12	ARIES Integrated dismantlement prototype	522d	10/2/95	9/30/97	5
13	OY Decon	522d	10/1/97	9/30/99	
14	Salt processing	522d	10/1/97	9/30/99	
15	Non-Pu component declass.	522d	10/1/97	9/30/99	
16	ZPPR fuel proc.	522d	10/1/97	9/30/99	
17	Integrated prototyping and eng	108w	10/1/99	10/25/01	12,13,14,15, 16
18	Conceptual design, NEPA , permitting	1660d	1/1/97	5/13/03	
19	Preferred site selection	48w	1/1/97	12/2/97	2
20	NEPA/EIS and site selection	660d	4/21/99	10/30/01	7,22
21	Permitting	320w	3/26/97	5/13/03	6,7
22	Conceptual Design	108w	3/26/97	4/20/99	6

Table 15. (continued).

Task no.	Task name	Duration	Start date	Finish date	Predecessors
23	Project authorization, Title I design, PSAR	780d	1/1/97	12/28/99	
24	KD#1 Approval for start	0d	1/1/97	1/1/97	2
25	Title I Authorization	0d	12/29/98	12/29/98	3
26	Title I Des & PSAR	36w	4/21/99	12/28/99	3,22
27	Documentation to DNFSB, review process, Title II des., FSAR, DNFSB release for construction	1200d	12/28/99	8/3/04	
28	KD#2- Start Title II Design	0d	10/30/01	10/30/01	4,20,26
29	Submit documentation to DNFSB	0d	12/28/99	12/28/99	26
30	DNFSB oversight process	240w	12/29/99	8/3/04	29
31	Title II Design & FSAR	60w	10/31/01	12/24/02	28
32	DNFSB approval/KD#3/Release for Construction	0d	8/6/03	8/6/03	30FS-52w
33	Construction, equipment installation, startup, test, ORR	832d	8/6/03	10/12/06	
34	Construction	120w	8/6/03	11/22/05	32
35	Procurement	92.2w	8/6/03	5/11/05	32
36	Equipment Installation	62.2w	9/2/04	11/10/05	35FS-36w,17
37	Startup, Preop testing, ORR	48w	11/11/05	10/12/06	34FS-24w,36
38	Operations	2400d	10/12/06	12/24/15	
39	KD#4 Commence Operation	0d	10/12/06	10/12/06	37,21
40	Operation	480w	10/13/06	12/24/15	39
41	D&D	720d	1/23/15	10/26/17	
42	D&D	144w	1/23/15	10/26/17	40FS-48w

Table 16. Immobilization facility schedule breakout.

Task no.	Task name	Duration	Start date	Finish date	Predecessors
1	Congressional funding and initial activities	1287d	10/2/95	9/5/00	
2	ROD KD 0 Approval for Mission Need	0d	1/1/97	1/1/97	
3	Congressional Funding Process	192w	1/1/97	9/5/00	2
4	R&D funding	0d	10/2/95	10/2/95	
5	A-E selection	12w	1/1/97	3/25/97	2
6	Select NEPA contractor	12w	1/1/97	3/25/97	2
7	R&D, demo, test, integrated prototyping and proc. eng	2500d	10/2/95	4/30/05	
8	Formulation, proc. & long term perf	175d	10/2/95	6/1/96	
9	Complete cold demonstration	0d	8/31/97	8/31/97	
10	Develop process parameters	522d	10/1/96	9/30/98	
11	Complete equipment conceptual	0d	9/30/98	9/30/98	
12	Hot demo equip. development	260d	10/1/96	9/30/97	
13	Hot demo operation	521d	10/1/97	9/30/99	12
14	Complete hot demo in FCF	0d	9/30/99	9/30/99	13
15	Waste form develop./char.	2261d	8/30/96	4/30/05	
16	Waste form risk OK to proceed	0d	5/6/02	5/6/02	15FS–156w
17	Balance of R&D, demo & test	1044d	10/1/96	9/29/00	
18	Integrated prototyping and eng	108w	10/2/00	10/25/02	17,14,13,12,11, 10,8
19	Conceptual design, NEPA, permitting	1600d	3/26/97	5/13/03	
20	NEPA/EIS and site selection	660d	4/21/99	10/30/01	6,22

Table 16. (continued)

Task no.	Task name	Duration	Start date	Finish date	Predecessors
21	Permitting	320w	3/26/97	5/13/03	5,6
22	Conceptual Design	108w	3/26/97	4/20/99	5
23	Project authorization, Title I design, PSAR	1573d	1/1/97	1/10/03	
24	KD#1 Approval for start	0d	1/1/97	1/1/97	2
25	Project Authorization	0d	9/5/00	9/5/00	3
26	Title I Des & PSAR	36w	5/6/02	1/10/03	21, 27, 16, 19
27	Documentation to DNFSB, review process, Title II des., FSAR, DNFSB release for construction	1200d	1/10/03	8/17/07	
28	KD#2- Start Title II Design	0d	5/3/04	5/3/04	20,26,16
29	Submit documentation to DNFSB	0d	1/10/03	1/10/03	27
30	DNFSB oversight process	240w	1/13/03	8/17/07	30
31	Title II Design & FSAR	60w	5/3/04	6/24/05	27, 29
32	DNFSB approval	0d	8/17/07	8/17/07	31
33	Approval to commence construction	0d	8/21/06	8/21/06	32FS-52w
34	KD#3/Release for Construction	0d	8/21/06	8/21/06	34
35	Construction, equipment installation, startup, test, ORR	832d	8/21/06	10/27/09	
36	Construction	120w	8/21/06	12/5/08	35
37	Procurement	92.2w	8/21/06	5/26/08	35
38	Equipment Installation	62.2w	9/18/07	11/25/08	38FS-36w, 18
39	Startup, Preop testing, ORR	48w	11/26/08	10/27/09	37FS-24w, 39
40	Operations	2400d	10/27/09	1/8/19	
41	KD#4 Commence Operation	0d	10/27/09	10/27/09	40, 22, 15
42	Operation	480w	10/28/09	1/8/19	42
43	D&D	720d	2/7/18	11/10/20	
44	D&D	144w	2/7/18	11/10/20	43FS-48w

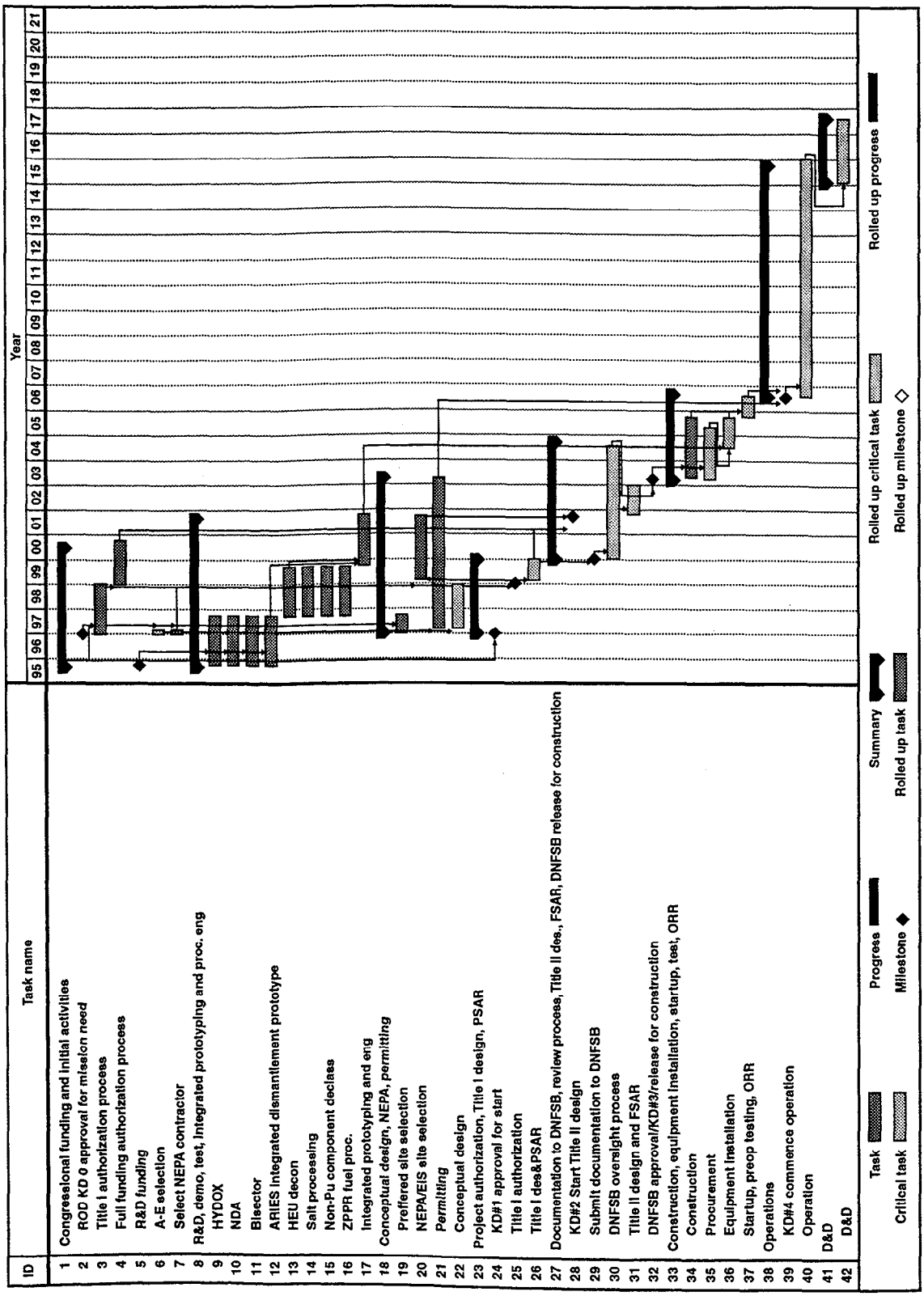

Figure 15. Front-end schedule.

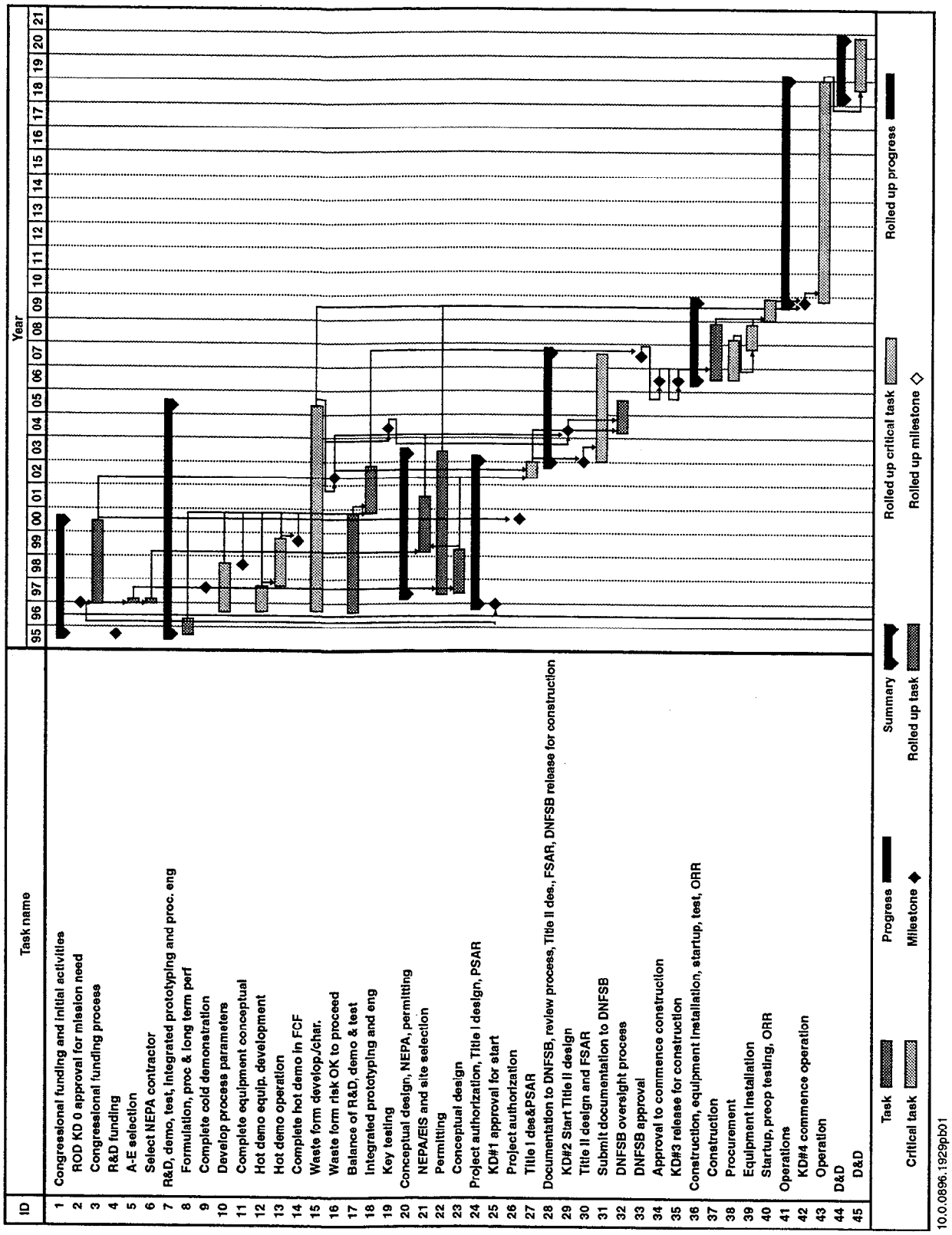

Figure 16. Back-end schedule.

Decontamination and decommissioning duration is included. The decommissioning method assumed for the schedule is complete dismantlement and restoration of the site for unrestricted use. Other methods (layaway, protective storage, etc.) or combinations of methods, depending on time, cost benefit studies, or radiation exposure, might be selected with an impact to the time required.

NRC Licensing. Since NRC licensing is only assumed for new facilities, the electrometallurgical treatment immobilization variant assumes DNFSB oversight. However, the same licensing activity duration will be used for modification of existing DOE facilities with DNFSB oversight. Licensing is a five-year long, key critical path activity. The schedule indicates nonsafety related construction starts a year prior to completion of this activity.

The schedule assumptions for NRC licensing are based on the Fluor Daniel report, *Regulatory Plans for NRC Licensing of Fissile Materials Disposition Alternatives*, Draft Revision A, June 26, 1995.

Although NRC licensing for processing is not applicable, there are two other distinct license types each with distinct issues to be addressed during the NRC licensing process for the electrometallurgical treatment immobilization variant. The types are shown below:

- Transportation, governed by 10 CFR Part 71
- Disposal, governed by 10 CFR Part 60

A brief discussion of the license types, extracted from the Fluor Daniel report, and their impact on the schedule follows.

Transportation. The regulatory requirements associated with transportation are well established and include consideration of the spectrum of transportation activities from small quantities of plutonium to very large amounts of plutonium. It should be noted that transportation of plutonium by commercial licensees, including the transport of plutonium for use as fuel in power reactors, has occurred. Thus, with respect to the activity of transportation of plutonium, a comprehensive set of regulatory requirements is established in the NRC regulatory system to implement the requirements of the Atomic Energy Act. Those regulations provide a well defined means to address the issues associated with transportation of large amounts of plutonium in the various elements of the DOE plutonium disposition program.

Container Certification. The immobilization variants require a licensed container for transportation. Use of an NRC-certified transportation container is a condition of the general license. The review and certification of the transportation container, when combined with DOT regulations regarding carriage, provides the means for the NRC to conclude that the means to transport the radioactive material does not compromise public health and safety. Transportation container certification is an independent licensing activity.

The Fluor Daniel report presents the base case schedule for NRC certification of a transportation container, which has a nominal two year duration, based on required procedural steps. Although there is provision for a hearing, it is unlikely to occur since no one, single community or area is impacted by the certification of a transport cask.

This activity for certification of a transportation container can be accommodated within the overall schedule.

A family of potential packages, 6M/2R-like packages, can be used for transporting the fissile material (excluding pits). These packages would require modification to insure that the package criteria stated in DOE-STD 3013-94 are met. Further modifications would be required to insure that the packaging configuration incorporates the primary containment vessel, analysis/testing is performed to show the abnormal and normal accident scenarios, the Safety Analysis Report (SAR) is modified to show the changes, and the package is certified for the material considering the packaging configuration.

Disposal. Following rule making or clarification in authorizing legislation for emplacing the immobilized forms in an HLW repository, a license amendment will have to be submitted to NRC for these waste forms. Further, the NEPA process which incorporates these wastes into a repository will also have to be followed.

2.7.2 Uncertainties

The preliminary, estimated schedule presented in tabular form in Table 13 and Table 14 and in Gantt chart form in Figure 15 and Figure 16 is a logic network defined by activity duration's and logical ties between them. As such, it lends itself to examination of the impacts in schedule variations. However, at this stage such analysis has not been done.

Permitting and Licensing. Any new facility will be regulated/licensed by NRC. However, DOE external oversight activities may influence the planning basis for use of existing facilities. The Advisory Committee on External Regulation of DOE Nuclear Facilities made recommendations to the Secretary on external regulation in early 1996. Recommendations from this committee will influence decisions on whether and what facilities will be regulated externally, and what external organization will be responsible. The DOE is currently preparing an action plan for implementing these recommendations. Decisions on external regulation could impact the permitting and licensing schedule durations. The same five-year critical path activity for licensing has been assumed for both new facilities or use of existing facilities.

Congressional Funding. The congressional funding cycle is a critical path activity. Improvements are not anticipated. However, delays would impact the overall disposition completion date.

R&D. The program identified to develop and demonstrate the immobilized formulation and process equipment will be better defined in the Long Range R&D plans

being prepared. However, relative to NEPA and other critical path activities the needed development and demonstration will either be readily achievable in time to support the baseline schedule, or critical problems that disqualify an variant will be identified early.

Waste Form Certification and Qualification. For the electrometallurgical treatment option, the waste form is viewed as less mature than glass or ceramics in terms of demonstrating suitability and presents a major technical and programmatic uncertainty. The probability that qualifying this waste form may be more difficult than glass or ceramics is reflected in a longer timeline to develop and qualify glass-bonded zeolite. Title II design is tied to key testing of the waste form towards the end of the qualification schedule of activities.

Site-Specific EIS and Permitting. For the use of existing ANL-W immobilization facilities, site-specific NEPA and other permitting activities are not shown as critical path activities, but would need to be monitored closely during implementation to determine if delays would impact the overall disposition completion date. Were an earlier determination to confirm the waste form is acceptable, a site-specific NEPA would likely become a critical path activity.

For the use of existing ANL-W front-end facilities, a site-specific NEPA is a critical path activity.

Title I & II Design, Procurement, Construction, and SAR Preparation. The use of existing ANL-W facilities offers opportunities to refine and improve on the schedule as more definition is achieved. Some are critical path activities, others may or may not impact the overall disposition completion date.

Cold Startup and Preoperational Testing. These activities offer opportunities to refine and improve on the schedule as more definition is achieved in the future. These are critical path activities, thus delays or improvements would impact the overall disposition completion date.

Hot Startup and Operations. These activities offer opportunities to refine and improve on the schedule as more definition is achieved in the future. Process improvements, plutonium immobilization experience, and increased plutonium loading could shorten the operational schedule. These are critical path activities, thus delays or improvements would impact the overall disposition completion date.

Decontamination and Decommissioning. These D&D activities occur after disposition and are not well defined at this point. While they are important to the conclusion of the overall program, they do not impact the overall disposition completion date.

Repository Availability. Uniform linear shipments to a HLW repository are assumed. However, the immobilization variant facilities planning basis includes storage for the entire inventory of dispositioned material. Thus material can be processed into the dispositioned form and stored until a HLW repository is available.

2.8 Institutional Issues

2.8.1 International Issues

In the United States, institutional issues have come to play every bit as important a role as technology in arriving at major federal decisions. It is vital that federal agencies, in developing policy initiatives, recognize the key roles that building public and political support and the timely satisfaction of requirements of process and openness play in the success or failure of programs and projects. Experience has shown that projects endorsed by selection processes that fail to take these factors into account may be seriously delayed or possibly never implemented. Therefore, agencies need to consider both the public process by which decisions are reached and the actions needed to build sufficient governmental, political, and public support, if they hope to achieve acceptance of the policy or program.

The ultimate measure of public support will be the successful implementation and completion of the plutonium disposition variants selected in the Record of Decision. However, even to formally adopt a policy and move toward implementation, a number of necessary steps will, in fact, become tests of public and governmental acceptance. An early test may arise when legislation is proposed to provide a statutory base for the program. In this case, political support will be established by a majority of votes cast in the Congress to pass legislation. The votes of elected representatives will be influenced by their perception of the attitudes of their constituents. Measuring public attitudes on political issues is an uncertain undertaking.

The need to take action is clear. The "no action" variant will not suffice. Plutonium exists and, in the long run, something must be done with weapons-grade plutonium to minimize the risk to proliferation. The purpose of the Fissile Materials Disposition Program is the proper, safe disposition of weapons plutonium to achieve these nonproliferation goals. While in the short term, only some of the plutonium materials must be dealt with on an urgent basis, early demonstration of one or more methods of disposition is important to establish programmatic momentum as soon as practicable. Early demonstration would also serve to show U.S. resolve in negotiations with Russia on disposition of Russian weapons plutonium.

2.8.2 Choice of Disposition Alternative

Under the immobilization alternative, surplus plutonium would be immobilized in an acceptable matrix to create a chemically stable form for disposal in a high-level waste repository. The immobilized form would also meet the spent-fuel standard in that the fissile material would be mixed with high-level wastes or other radioactive isotopes and immobilized to create a radiation field that could serve as a proliferation deterrent comparable to commercial spent nuclear fuel.

However, we cannot pursue the problem of disposing of our tens of metric tons of excess U.S. separated plutonium in a vacuum. There is a very important international context:

- Excess Russian weapons plutonium. Russia has even more excess weapons plutonium than the U.S.
- Separated civil plutonium. Russia, Western Europe, Japan, and India have in addition, a combined total of about 100 tons of separated civilian, but weapons-usable plutonium. This inventory is still increasing at a rate of 15 tons per year as the rate of separation of plutonium from power-reactor fuel still greatly exceeds the rate at which it is being fabricated into mixed-oxide fuel.

There currently appears to be little question in the minds of foreign nuclear energy establishments as to how they will dispose of their separated plutonium:

- *West Europe.* Virtually all plutonium separated from West European power-reactor fuel is to be fabricated into MOX fuel for light-water power reactors;
- *Japan.* Most of the plutonium separated from Japanese power-reactor fuel is to be similarly recycled into MOX fuel for light-water reactors with the remainder being fabricated into MOX fuel for Japan's demonstration fast-neutron and advanced-converter reactors.
- *Russia.* Russia's nuclear energy establishment also expects to fabricate its excess weapons plutonium and separated power-reactor plutonium into MOX fuel for reactors but has not moved decisively to do so. Before the collapse of the Soviet Union, the plan was to use the civilian plutonium as startup fuel for a new generation of fast-neutron plutonium breeder reactors. That is still the plan of a significant part of Russia's nuclear establishment but it is not clear at this time where the funds to build these reactors would come from.

The international implications of U.S. plutonium disposition strategy deserves both analysis and public debate. A primary objective of the technical evaluation process will be to prepare the United States to engage Russia, and other nations with relevant interests and experience in efforts that would lead to making reuse of the plutonium for weapons much more difficult.

The Administration's nonproliferation policy states that the United States does not encourage the civil uses of plutonium and does not itself reprocess plutonium for either nuclear power or nuclear explosive purposes. However, the policy also states that the U.S. will maintain its existing commitments regarding the civil use of plutonium in Western Europe and Japan. In addition, the policy commits the U.S. to explore means to limit the stockpiling of plutonium from civil nuclear programs and to seek to minimize the civil use of highly enriched uranium.

Since it is assumed that the disposition program is to be carried out under some degree of transparency and reciprocity, negotiations must be carried out to arrive at mutually acceptable conditions to preclude unintentional unilateral disarmament.

2.8.3 Sociopolitical Issues

Inspection by the IAEA. As noted by the NAS study, efforts to stem the spread of nuclear weapons are critically dependent on the strength and credibility of the systems and organizations given the responsibility to carry them out. One of the "key elements" of the President's September 27, 1993 Nonproliferation and Export Control Policy is to "submit U.S. fissile materials no longer needed for our deterrent to inspection by the International Atomic Energy Agency." Inspection by IAEA will provide added assurance to the public that all fissile material is accounted for and that risks of theft and proliferation are minimized. The IAEA's traditional approach to safeguards focused on verifying declared facilities at declared sites. Even though the IAEA has always had statutory authority to inspect other sites, support from its key member states has not been sufficient to enable it to do so meaningfully to date. The IAEA does not have an enforcement or security function but rather it provides independent accounting and auditing functions. To participate in monitoring fissile materials released from nuclear weapons programs, IAEA will need greater resources.

2.8.4 Environment, Safety, and Health Issues

According to the NAS report, "the greatest dangers to public welfare associated with the existence and disposition of weapons plutonium are unquestionably those connected with national and international security. The preeminence of these security dangers, however, should not obscure the need for careful attention to the environment, safety, and health (ES&H) risks implied by the different approaches to weapons dismantlement, fissile materials storage, and long-term disposition of weapons plutonium."

The Stabilization Program is assumed to convert the plutonium to a form compatible with the DNFSB Recommendation 94-1. The short-term ES&H concerns must be coordinated with the nuclear nonproliferation objectives. The December 1995 *Plutonium Stabilization and Immobilization Workshop* is an example of the ongoing effort needed to maintain communication and promote a common understanding on stabilization and immobilization technology requirements.

New and more stringent ES&H regulations are being imposed on the U.S. nuclear weapons complex. These are dynamic standards, and can be expected to continue to change over time. Currently, ES&H requirements set the pace for each stage of plutonium processing throughout the immobilization processes. The time required to implement any immobilization choice will be heavily influenced by the licensing and approval processing, including the extended safety and environmental analysis required for each option. Ultimately, these ES&H standards will affect the ease and cost of achieving different immobilization options.

2.9 Hybrid Option—Zeolite

The features of the ET alternative provide corresponding advantages relative to some other approaches. The key advantages are discussed below.

2.9.1 Direct Immobilization of Halide Residues

Some of the plutonium in the inventory of surplus material is associated with halide (mostly chloride) salts. Because the ET process is designed to stabilize chloride waste for repository disposal, the technology for handling chlorides is already established. It is possible that the chloride residues can be placed directly into the zeolite/glass waste form with minimal pretreatment (such as drying and filtration). The ET option could provide a simple solution for treatment and immobilization of this residue stream.

CE-21 Chloride Feed Preparation. The chloride residues are assumed to be relatively dry, and they are assumed to contain some plutonium metal, and oxides. Some of the salts are also likely to contain various amounts of calcium metal, calcium oxide, and possibly other alkali or alkaline earth metals and oxides. The salts that contain free alkali or alkaline earth metals will be melted and sparged with oxygen to convert these residual metals to oxides. The salts will then be filtered. The filtered oxide particles will be fed to lithium reduction, Step CE-22. The filtered salts will be mixed with $PuCl_3$ from Step DC-06 and fed to the salt blend tank, Step CE-25.

2.9.2 Zeolite Option

A variation of the electrometallurgical treatment (ET) variant could be used as a stand-alone option for immobilization of surplus plutonium, independent of treatment of the DOE spent nuclear fuel. This stand-alone process, called the zeolite option, is similar to the ET variant in every aspect except for substitution of a chlorination step that is operated in a glove box for the electrorefining step that is operated in a shielded facility. In the zeolite option, the metal and metal alloy feed materials are converted to chlorides (primarily $PuCl_3$) in solution in LiCl-KCl eutectic; the oxide feed materials are reduced to metals using lithium reductant, then the reduced metal product is converted to chlorides. The chloride feeds are then blended with $^{137}CsCl$ from the Hanford capsules and the other chlorides.

These blended chloride salts are sorbed on zeolite to make a dry, ceramic powder. The zeolite powder is blended with glass frit and hot pressed to make the glass-bonded zeolite immobilization form. The second-level flow diagram for the zeolite option is shown in Figure 17. The only differences between this flow diagram and the ET second level flow diagram: 1) the electrorefiner, CE-24, in the FCF hot cell is eliminated, and 2) a chlorination step, CE-24, is added to the FMF glove box complex. Details concerning the new chlorination step are discussed in the following paragraphs.

Chlorination Step, CE-24. Conversion of plutonium (and americium, neptunium, and curium) to the trichloride can be done by a variety of methods. The method that was chosen for this step has the advantages of ease of operation and minimization of

materials corrosion concerns. While two steps are shown, chlorination of zinc and chlorination of plutonium, both steps are actually done in a single container in sequential operations. The container initially contains zinc with a covering LiCl-KCl eutectic salt bath plus $ZnCl_2$. Plutonium (or other TRU elements) metal is added to the container, and the mixture is stirred to promote reaction to form $PuCl_3$ and additional zinc metal. A slight excess of plutonium is added to assure that all of the $ZnCl_2$ is consumed, and the excess plutonium dissolves in the zinc heel. The salt phase, containing the $PuCl_3$, is transferred to the salt blend tank, CE-25, and the zinc heel remains behind.

The next charge of LiCl-KCl eutectic mixture is added, and the melt is sparged with chlorine (in a suitable carrier gas) to convert the remaining plutonium and some of the zinc heel (for each plutonium charge) to the chlorides. The container is now ready for the next batch of plutonium metal. The quantities shown in Figure 16 are the daily throughput for the process, not the quantities for each batch.

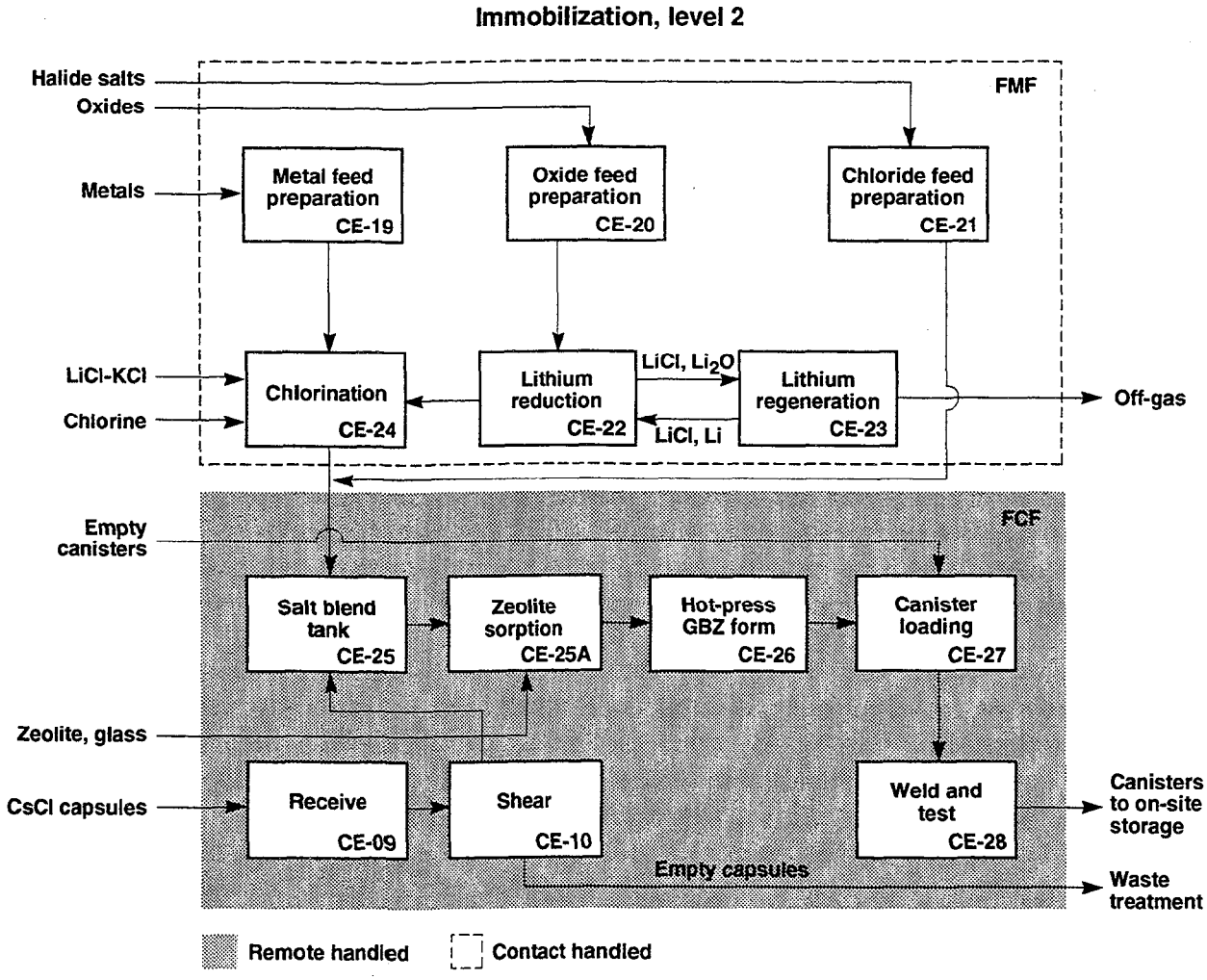

Figure 17. Hybrid option, zeolite.

Remaining Process Steps. The steps, CE-l9 through CE-23, before the chlorination step are unchanged from the ET Variant. Subsequent steps, CE-25 through CE-28, CE-09, and CE-10, are unchanged, except that the quantities of materials handled are slightly decreased.

This decrease is because there is no need to handle nor immobilize the spent fuel waste stream. Only the plutonium and cesium capsule materials are treated in the zeolite option.

All the remaining flow diagram steps are identical to the corresponding steps for the ET variant, so they are not repeated here.

Advantages of the Zeolite Option. The motivation for considering the zeolite option along with the electrometallurgical treatment variant is its simplicity and the compact equipment required to complete the plutonium immobilization task. The chlorination step is smaller than the electrorefiner, and the design is very simple. The chlorination operation can be done in a small crucible, and the zinc acts as a buffer for reducing the corrosion potential of the chlorine environment.

The existing ANL-W facilities are suitable for this operation, and the schedule for plutonium immobilization is compatible with completion of the spent fuel treatment activities. Since the chlorination operation is outside the shielded facility, the concerns of chlorine release to the hot cell is eliminated. Elimination of the electrorefining operations from the hot cell further simplifies the process over the ET variant.

3.0 Acronyms

AE	Architect - Engineer
ANL-W	Argonne National Laboratory-West
ALARA	As Low As Reasonably Achievable
ANSTO	Australian Nuclear Science and Technology Organization
ARIES	Advanced Recovery and Integrated Extraction System
CCC	Ceramic Can-in-Canister
C/S	Containment and Surveillance
CCTV	Closed Circuit Television
CFR	Code of Federal Regulations
CGF	Ceramic Greenfield Facility
CRT	Container Restraint Transport
CRWMS	Civilian Radioactive Waste Management System
D&D	Decontamination and Decommissioning
DHLW	Defense High-Level Waste
DOE	Department of Energy
DOT	Department of Transportation
DP	Defense Programs
DWPF	Defense Waste Processing Facility
EM	Environmental Management
ER	Electrorefiner
ET	Electrometallurgical Treatment
EIS	Environmental Impact Statement
FCF	Fuel Conditioning Facility @ ANL-W
FM	Fissile Material
FMDP	Fissile Materials Disposition Program
FMF	Fuel Manufacturing Facility @ ANL-W
FSAR	Final Safety Analysis Report
GBZ	Glass-Bonded Zeolite
GMODS	Glass Materials Oxidation Dissolution System
Gy	Gray
HEME	High-Efficiency Mist Eliminator
HEPA	High-Efficiency Particulate Air (filter)

HFEF	Hot-Fuel Examination Facility @ ANL-W
HLW	High-Level Waste
HVAC	Heating, Ventilating, and Air Conditioning
HYDOX	Hydride Dehydrite Oxidation
IAEA	International Atomic Energy Agency
INEL	Idaho National Engineering Laboratory
ISG	International Safeguards
KD	Key Decision
LCC	Life-Cycle Costs
LLNL	Lawrence Livermore National Laboratory
LLW	Low-Level Waste
MAA	Materials Access Area
MAUA	Multi-Attribute Utility Analysis
MBA	Material Balance Area
MC&A	Materials Control and Accountability
MD	Materials Disposition
MEO	Mediated Electrochemical Oxidation
MOX	Mixed Oxide: (U, Pu) O_2
MPC	Multi Purpose Container
MSO	Molten Salt Oxidation
NAS	National Academy of Sciences
NDA	Non-Destructive Analysis
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
OCRWM	Office of Civilian Radioactive Waste Management
ORR	Operation Readiness Review
OY	Oralloy
PA	Protected Area
PCV	Primary Containment Vessel
PEIS	Programmatic Environmental Impact Statement
PSAR	Preliminary Safety Analysis Report
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
RSWF	Radioactive Scrap and Waste Facility @ ANL-W
SAR	Safety Analysis Report

S&S	Safeguards & Security
SCFM	Standard Cubic Feet per Minute
SGT	Safeguard Transporter
SNF	Spent Nuclear Fuel
SNM	Special Nuclear Material
SQ	Significant Quantity
SRS	Savannah River Site
SST	Safe Secure Trailer/Transport
SYNROC	Synthetic Rock
TID	Tamper Indicator/Indication Device
TRU	Transuranic
TSLCC	Total Life-Cycle Cost
TTP	Technical Task Plan
VAM	Vitrification Adjunct Melter
VCC	Vitrification Can-in-Canister
VGF	Vitrification Greenfield Facility
WAO	Wet Air Oxidation
ZPPR	Zero Power Physics Reactor @ ANL-W